The two sides of the same coin:
introduction of technology in SMEs

Camila Silva de Mattos

Propositions

1. Policymakers must recognize the importance of business model adaptation for successful technological transformation in the agrifood system.
   (this thesis)
2. Small and medium enterprises are highly dependent on their context, limiting their ability to strategically benefit from technological transformation.
   (this thesis)
3. The academic journey is best navigated proactively, rather than with a wait-and-see approach.
4. Research with impact is only achievable when intermediaries bridge the gap between research and practice.
5. Despite the inevitability of death, society struggles to prepare for and provide meaningful support to mourners.
6. Decision-making and problem-solving capabilities are significantly enhanced when one applies intuition.

Propositions belonging to the thesis, entitled

The two sides of the same coin: introduction of technology in SMEs

Camila Silva de Mattos
Wageningen, 24 June 2026

The two sides of the same coin: introduction of technology in SMEs

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This research was conducted under the auspices of the Graduate School of the Wageningen School of Social Sciences (WASS).

The two sides of the same coin: introduction of technology in SMEs

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Thesis

Submitted in fulfilment of the requirements for the degree of doctor

at Wageningen University

by the authority of the Rector Magnificus,

Prof. Dr C. Kroeze,

in the presence of the

Thesis Committee appointed by the Academic Board

to be defended in public on

Wednesday 24 June 2026

at 3.30 p.m. in the Omnia Auditorium.

Camila Silva de Mattos
The two sides of the same coin: introduction of technology in SMEs

PhD thesis, Wageningen University, Wageningen, the Netherlands (2026)
With references, with summary in English
DOI: https://doi.org/10.18174/681113

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List of abbreviations

AC → Active coating

BM → Business model

BMI → Business model innovation

CoC → Chamber of commerce

CRM → Customer relationship management

CSA → Climate Smart Agricultural

CSPs → Critical strategic points

DOI → Diffusion of innovation theory

EP → Electroperoxidated water

ERP → Enterprise Resource Planning

EW → Electrolyzed water

F&V → Fruits and vegetables

HPP → High-Pressure Processing

NTPTs → Non-thermal processing technologies

PAW → Plasma-activated water

PDO → Protected Designation of Origin

PEF → Pulsed electric field

RBV → Resource-Based View

SLR → Systematic literature review

SMEs → Small and medium-sized enterprises

TA → Technology assimilation

TAM → Technology acceptance model

TOE → Technology Organization and Environment

TPs → Technology providers

US → Ultrasound

WOS → Web of Science

1

General introduction

Chapter 1. General introduction

1.1. Introduction

The current global business environment is characterized by continuously evolving dynamics, including new regulations, technological advancements, increased competition, rising product demand, globalization, and recent disruptions such as the COVID-19 crisis and the Fourth Industrial Revolution (Subriadi & Wardhani, 2022; Ragazou et al., 2022). This constantly changing landscape, coupled with stringent industrial standards, poses requirements and challenges for companies, pushing them to continuously evaluate and innovate their production methods to remain competitive and ensure survival (Paoloni et al., 2022; Akpan et al., 2022).

In response to these requirements and challenges, companies are driven to introduce new technologies, which are associated with numerous potential benefits, including enhanced competitiveness, sustainable growth, firm expansion, and positive economic impact (Popa et al., 2018; Akbari et al., 2021). Consequently, the significance of technological innovation has grown over the past decades, receiving substantial attention and becoming a pivotal area in business research (Pan et al., 2019; Akbari et al., 2021).

Despite the growing research attention and the widely recognized potential benefits of technological innovation, further research is necessary to understand how companies can effectively convert this potential into tangible improvements in performance and competitiveness (Pavic et al., 2007; Chen et al., 2018; Merín-Rodrigáñez et al., 2024). Several studies within the extensive and multidisciplinary field of technological innovation indicate that to benefit from introducing new technologies, companies need to engage in both technology assimilation[1] and business model innovation (BMI) processes (Baden-Fuller & Haefliger, 2013; Smajlović et al., 2019; Pellegrini et al., 2023; de Mattos et al., 2024).

Technology assimilation refers to the process through which organizations incorporate technologies into their operations, from initial awareness to full implementation (Zhu et al., 2006; Baird et al., 2017). This process is crucial for ensuring that these technologies are properly integrated and utilized, allowing companies to fully benefit from them (Pellegrini et al., 2023). BMI is the process of adapting or transforming a company's business model (BM) to exploit technological opportunities, which is required to bridge the gap between technology

[1] The term "technology assimilation" is used to provide consistency and unify various terms found in the literature — such as technology adoption, technological innovation, and technology implementation — that describe the introduction of technologies into organizational processes. This standardization addresses the multidisciplinary and fragmented nature of the field (de Mattos et al., 2024; Pellegrini et al., 2023).

introduction and competitive advantage (Chesbrough, 2007; Teece, 2010; Foss & Saebi, 2017; Alojairi et al., 2019).

Research consistently indicates that technology assimilation and BMI processes are interconnected and complementary when introducing new technologies (Chesbrough, 2007; Baden-Fuller & Haefliger, 2013; Tongur & Engwall, 2014; Holzmann et al., 2019). These connections include (Smajlović et al., 2019; Sabatini et al., 2022; de Mattos et al., 2024): the assimilation of new technology often leads to changes in operational and commercial activities, necessitating adaptations in how organizations organize their business; as companies modify their BMs to capitalize on technological opportunities, BMI acts as a link between technology assimilation and organizational performance; and BMI activities prompt organizations to search for innovation strategies, including the introduction of new technologies.

Although there is consensus that technology assimilation and BMI are intertwined and essential components of the organizational process for leveraging new technologies, the literature often addresses these processes separately (Baden-Fuller & Haefliger, 2013; Smajlović et al., 2019). Consequently, the comprehensive organizational transformation resulting from technology introduction remains abstract and lacks clear conceptualization, a limitation that is especially pronounced in the context of small and medium-sized companies (SMEs)[2], where this line of research is relatively underdeveloped (de Mattos et al., 2024).

Recently, research on digital transformation has started to integrate technology assimilation and BMI into a more cohesive framework, reflecting the growing importance and necessity of digital technologies. Studies have examined how organizations incorporate these technologies while simultaneously adapting their BMs, highlighting their synergistic effects on organizational innovation and competitive advantage (e.g., Warner & Wäger, 2019; Singh et al., 2020; Vial, 2021). However, these contributions are limited, focusing primarily on digital technologies and not extending to broader technological contexts. Moreover, research on digital transformation often overlooks SMEs (Petzolt et al., 2022).

To encompass a broader context, this thesis introduces the term "technological transformation", which, while analogous to "digital transformation", covers a broader spectrum of technologies. This term captures the process of organizational change driven by the introduction of technologies, including but not limited to digital technologies.

[2] The thesis follows the EU definition of SMEs (European Commission, 2003), which classifies companies into three categories based on both employee count and turnover: micro companies (0-9 employees and a turnover of up to €2 million), small companies (10-49 employees and a turnover of up to €10 million), and medium-sized companies (50-249 employees and a turnover of up to €50 million).

Technological transformation remains underexplored within the context of SMEs, which present a particularly valuable setting for study due to their critical need to introduce new technologies, their societal and economic importance, and the significant constraints they face compared to larger counterparts. The primary objective of this thesis is to develop a comprehensive framework that integrates technology assimilation and BMI to assist SMEs in understanding and managing the technological transformation process driven by technology introduction. The title of this thesis — "The two sides of the same coin: introduction of technology in SMEs" — reflects this holistic approach, emphasizing the intertwined nature of technology assimilation and BMI. By examining both processes together, this research aims to provide a unified perspective on the technological transformation process within SMEs. Building on this holistic approach, the next section presents the problem statement, which further defines the research gaps this thesis seeks to address.

1.2. Problem statement

The overarching research gap of this thesis is the limited understanding of the technological transformation process in SMEs (Pellegrini et al., 2023; de Mattos et al., 2024). The general objective of this thesis is to enhance the understanding of the technological transformation process in SMEs, specifically focusing on the integration of technology assimilation and BMI by developing a conceptual framework.

Addressing this overall research gap of this thesis — the limited understanding of the technological transformation process in SMEs — is relevant for several reasons. SMEs significantly contribute to global economies and employment (Cantele et al., 2020). SMEs are under pressure to introduce new technologies to respond to diverse demands, changes, and opportunities, attempting to enhance their competitiveness and ensure survival in a dynamic business environment (Akpan et al., 2022; Donbesuur et al., 2020; Priyono et al., 2020; Paoloni et al., 2022; Prasanna et al., 2019). However, SMEs face several challenges in integrating and exploiting new technologies, such as resource and skills constraints (Brink, 2017), time limitations, and managing the complexities of technological transformation (O'Toole, 2003; Bouwman et al., 2019; Müller et al., 2021). These challenges can severely impact their performance and, consequently, impact their economic and societal contributions (Liang et al., 2007; Pellegrini et al., 2023).

This thesis aims to respond to this overarching research gap by addressing **three specific gaps** in three different interconnected studies presented respectively in **Chapters 2, 3, and 4**. The **first** research gap is the fragmented and vague understanding of the technological

transformation phenomenon in SMEs. Despite the studies recognizing the complementarity between technology assimilation and BMI, the literature remains disjointed and unclear (Smajlović et al., 2019; Sabatini et al., 2022), largely due to the separation of related fields and limited exploration of the SME context. More specifically, existing literature reviews often focus on separate research streams of technology assimilation (Ahmad & Siraj, 2018) and BMI (Hidayat et al., 2020). Other studies frequently address specific aspects such as factors (Groot et al., 2019; Ibarra et al., 2020), BM configurations (Jutla et al., 1999; Laplume et al., 2016), and case studies (Jutla, 1999; Alexander, 2003; Priyono et al., 2020). These narrow foci prevent a comprehensive view of the technological transformation phenomenon. Furthermore, the individual streams of BMI (Pucihar et al., 2019; Gatautis et al., 2019) and technology assimilation (Ahmad & Siraj, 2018) are underexplored within the SME context, significantly limiting the current scientific literature on technological transformation in SMEs. In response to this gap, a systematic literature review was conducted, identifying the second and third literature gaps presented below.

Addressing this **first** research gap is crucial for achieving concept clarity. The current literature's limited exploration and disjointed approach limit understanding of technological transformation in SMEs, hindering a full comprehension of its antecedents, process, and outcomes. Scholars emphasize the importance of clear concepts and constructs to make complex phenomena more manageable and comprehensible, which facilitates research coordination, operationalization, measurement, and cumulative progress (Suddaby, 2010; Foss & Saebi, 2017). This gap restricts practical guidance for SME managers and policymakers, as the concept of technological transformation remains abstract and poorly integrated, underscoring the need for unified, concrete definitions and detailed, actionable insights.

The **second** research gap is the lack of a comprehensive analysis of how SMEs respond to the introduction of technologies and their outcomes (Sabatini et al., 2022; de Mattos et al., 2024), particularly in the agri-food sector (Pellegrini et al., 2023). Most studies on technological transformation in SMEs focus on factors influencing decision-making, especially barriers (e.g., Birkel et al., 2019; Fanelli, 2021; Indrawati et al., 2020; Kumar et al., 2022) and drivers (e.g., Bracci et al., 2022; Mujahed, 2022). Consequently, there is a lack of empirical insights on the entire technological transformation process, from decision-making to outcomes (de Mattos et al., 2024). In agri-food SMEs, the body of knowledge on the technological transformation process is even less developed, with existing studies often focusing either on technology assimilation (e.g., Abecassis et al., 2018) or BMI (e.g., Ulvenblad et al., 2018), but not both,

further limiting the understanding of their experiences, outcomes, and the conditions influencing them.

The relevance of addressing this second research gap lies in the critical importance of the EU agri-food sector, predominantly composed of SMEs, which face urgent needs to introduce technologies for food safety, quality, and globalization (Minarelli et al., 2015). These SMEs struggle with technological transformation due to limited resources and capabilities (Minarelli et al., 2015; Pellegrini et al., 2023). Additionally, the dynamics of the technological transformation process from initiation to outcomes are not well understood in SMEs (de Mattos et al., 2024), particularly in the agri-food sector (Pellegrini et al., 2023). By analyzing multiple cases, this study uncovers patterns related to the technological transformation process and its outcomes, as well as the associated conditions. Understanding how technological, environmental, and organizational conditions affect outcomes obtained throughout the technological transformation process enables managers to plan and manage technological transformations more effectively. Additionally, identifying these innovation patterns paves the way for future research, enabling the application of findings to similar firms and the creation of classification systems for technological transformation within specific contexts or sectors. This ongoing research has the potential to enhance understanding of technological transformation, leading to more effective strategies to boost SMEs' success in their innovation efforts.

The **third** literature gap is the insufficient definition and representation of the technological transformation process, with existing studies offering abstract descriptions and lacking structured frameworks to support SMEs (Sabatini et al., 2022; de Mattos et al., 2024). This gap extends beyond SME-focused literature, as structured approaches often emphasize the BMI side within the broader technological transformation process (e.g., Pateli & Giaglis, 2005; Wirtz & Daiser, 2018). As a result, there is a notable lack of integrative representations of the technological transformation process and practical guidance for planning and executing these transformations, particularly for SMEs.

The relevance of addressing the third research gap lies in clarifying the concept of the technological transformation process with greater specificity. Unlike the first gap, which offered preliminary insights into integrating technology assimilation and BMI, this gap emphasizes a deeper integration and detailed exploration of the entire transformation process, including its phases, tools, steps, and activities. The developed framework bridges the gap between academic theory and practical application, offering a structured approach for both theoretical advancement and practical implementation (Eisenhardt, 1989; Kieser & Nicolai, 2005). This framework not only enhances theoretical understanding but also provides a general,

adaptable protocol for practitioners, facilitating the management of technological transformation for SMEs.

1.3. Research aims and questions

The general objective of this thesis is to enhance the understanding of the technological transformation process in SMEs by developing a comprehensive framework that aids in both understanding and facilitating its management. Therefore, the overarching research question of this thesis is: *How can an integrative framework for the technological transformation process be developed to support and guide the organizational transformation that SMEs undergo when introducing new technologies?*

This thesis addresses the overarching research question through three interconnected studies. The first study, detailed in Chapter 2, is a systematic literature review on technological transformation in SMEs, guided by the primary research question: *What is the state of the art in the literature on technological transformation in SMEs?* This review analyzes 165 peer-reviewed papers published from 1999 to 2022, covering technology assimilation and BMI constructs.

This literature review employs inductive content analysis, an approach particularly suited to discerning emerging themes and patterns in the fragmented, multidisciplinary field, thereby providing a comprehensive understanding. This study outlines the overall structure of technological transformation by integrating technology assimilation and BMI structures, thereby making previously vague and dispersed descriptions more concrete and enhancing understanding of the phenomenon. This study systematically identifies and defines the critical elements of technological transformation, including drivers, barriers, controls, processes, enablers, and outcomes. The analysis culminates in the creation of a general framework that cohesively organizes these elements into a visual, sequential structure. These insights serve as a foundation for the next two studies. Moreover, this literature review maps the main research lines in the field and identifies existing gaps, setting the stage for subsequent investigations to address them.

The second study was guided by the overarching research question[3]: *How do EU agri-food SMEs assimilate new technologies, innovate their business models, perceive performance, and what conditions influence their transformation levels and performance perceptions?*

[3] To simplify and enhance cohesion, the research questions from the second and third studies have been consolidated into overarching questions. Specifically, the two questions from the second study are combined into one, and the three questions from the third study are merged into another. This approach streamlines the presentation and maintains a clear focus on each study's key inquiries.

This question is addressed in Chapter 3 through a multiple-case study involving 39 agri-food SMEs, focusing on their technological transformation trajectories. More specifically, this study examines their transformation outcomes (levels of BMI, levels of technology assimilation, and perceived performance), along with the key conditions in the organizational, technological, and environmental contexts that influenced the attainment of these outcomes. This second study provided empirical insights that informed the third study. Specifically, the qualitative study revealed key barriers and anticipated changes in BMs from experienced agri-food SMEs. These findings were used as input for developing BM prototypes and innovation strategies in the third study, which focused on pilot agri-food SMEs new to technological transformation.

Building on these insights, the third study addresses the overarching research question: *How can a conceptual framework be structured to include relevant concepts, phases, and tools to represent the technological transformation process and assist SMEs in understanding and undergoing it, and to what extent does its application validate its logical coherence, enhance understanding of the process, and uncover previously unidentified insights?*

This question is addressed in Chapter 4, which details the framework developed through an exploratory conceptual development approach combining systematic and iterative literature analysis with qualitative empirical validation. This chapter develops and empirically examines a four-phase framework for technological transformation, specifying key activities, inputs, and outputs. Drawing on retrospective qualitative evidence from 20 EU agri-food SMEs and insights from technology providers, the analysis identifies SME specific conditions shaping the framework's application. The framework is then applied to three pilot SMEs at early stages of transformation, illustrating how decisions, activities, and constraints unfold in practice and helping reduce the abstraction of the process. Overall, the chapter demonstrates the framework's value as a structured yet flexible reference for understanding and planning technological transformation in SMEs.

1.4. Thesis structure

This work is organized into five chapters. Chapter 1 presents the initial considerations of this thesis. Chapter 2 presents a systematic literature review of technological transformation in SMEs, detailing the literature analysis and identifying gaps that the subsequent two chapters will address. Chapter 3 presents a multiple-case study with agri-food SMEs, exploring their processes, outcomes, and influencing conditions. Chapter 4 develops and applies a framework for the technological transformation process using qualitative data from three agri-food SMEs.

Chapter 5 discusses and concludes with the main findings, limitations, and suggestions for future research.

1.5. Research context: Shealthy project

This research was conducted in alignment with the SHEALTHY project (2019-2023), an initiative funded by the European Union's Horizon 2020 program. The project aimed to support agri-food SMEs in identifying and experimenting with tailored combinations of non-thermal technologies to sanitize, preserve, and stabilize their food products. These technological solutions were specifically designed to enhance food safety, maintain nutritional quality, and extend shelf life, thereby satisfying consumer demand for fresh, healthy, and convenient options. By tailoring these technologies to each SME's specific needs and enabling them to test these innovations, the project facilitated strategic decision-making, helping businesses align technological advancements with their goals and ultimately improving their competitiveness.

The SHEALTHY project brought together a diverse consortium of international research partners, including universities, research institutes, and technology providers, facilitating collaboration and integration with participating companies across Europe. This PhD research contributed to key project activities and deliverables by providing a range of insights. It deepened the understanding of expectations and opportunities for participating SMEs, provided an analysis of technological transformation patterns informed by both literature and volunteer agri-food SMEs, presented existing BMs alongside the development of prototypes and innovation strategies, and created a process framework that clarified technological transformation activities while integrating insights from various work packages into a unified approach. In sum, this PhD research provided valuable insights that advanced the project's broader objectives and contributed to its activities and reports.

2

Systematic literature review on technological transformation in SMEs: a transformation encompassing technology assimilation and business model innovation

Chapter 2. Systematic literature review on technological transformation in SMEs: a transformation encompassing technology assimilation and business model innovation

Abstract

Small and medium-sized enterprises (SMEs) are pushed to introduce new technologies due to different requirements and changes in the business setting. The SMEs' transformation to exploit new technologies is challenging given their lack of resources and the complexity of technological transformation, which encompasses technology assimilation and business model innovation (BMI). Although studies recognize the complementarity of technology assimilation and BMI for benefiting from technology, the literature is fragmented, and the technological transformation phenomenon remains abstract, especially in the SMEs' context. To improve understanding of technological transformation in SMEs, a systematic literature review was performed on 165 peer-reviewed papers published from 1999 to 2022, building upon BMI and technology assimilation constructs. The descriptive analysis outlines the field's evolution in terms of research and technological trends. The content analysis shows that: most papers focus on factors; the literature falls short of providing theoretical conceptualization and guidelines for the technological transformation process; only a few studies are dedicated to assessing the outcomes of technological transformation in SMEs; and the papers suggest that SMEs present a low transformation level. Finally, we inductively built a framework for technological transformation and suggest five research avenues.

Keywords

Technological transformation; Technology assimilation; Business model innovation; SMEs; Technological innovation; Systematic literature review

This chapter is published as

de Mattos, C. S., Pellegrini, G., Hagelaar, G., & Dolfsma, W. (2024). Systematic literature review on technological transformation in SMEs: a transformation encompassing technology assimilation and business model innovation. *Management Review Quarterly.* https://doi.org/10.1007/s11301-023-00327-7

2.1. Introduction

The current business setting characterized by environmental changes, new requirements, technological development, and new opportunities pushes SMEs to rethink their traditional production methods and introduce new technologies to remain competitive over time (Paoloni et al., 2022; Priyono et al., 2020). However, introducing a new technology is challenging for SMEs with limited access to external knowledge, unclear innovation strategies (Müller et al., 2021), and scarce time and resources for innovation (Bouwman et al., 2019). Indeed, studies have shown that SMEs struggle to exploit and benefit from new technologies (O'Toole, 2003; Nguyen et al., 2015).

Studies highlight the need for technology assimilation[4] (Baird et al., 2017) and BMI (Alojairi et al., 2019) for SMEs to benefit from new technology. Technology assimilation is needed for efficient technology use (Baird et al., 2017), and BMI is required to exploit the opportunities offered by the technology (Alojairi et al., 2019), as technology per se is not enough to provide value for companies.

In fact, technology assimilation and BMI are not independent of each other, but they interact when introducing new technology, and their interconnectedness is crucial for performance (Smajlović et al., 2019). However, although the complementarity between technology assimilation and BMI for exploiting new technology is acknowledged by previous studies (Chesbrough, 2007; Baden-Fuller & Haefliger, 2013), little attention has been devoted to connecting these two concepts (Smajlović et al., 2019), especially in the context of introducing technology (Sabatini et al., 2022). To conceptually express the organization's transformation due to the introduction of technology (including technology assimilation and BMI), we denominate it as technological transformation.[5]

Technological transformation as a research field is fragmented and lacks explicit academic attention, especially in the SMEs' context: existing literature reviews focus on the separate streams of technology assimilation (e.g., Ahmad & Siraj, 2018) or BMI (e.g., Hidayat et al., 2020). Moreover, studies within this context focus on aspects of BMI or technology assimilation, such as factors or business model (BM) configurations (e.g., Jutla, 1999; Groot et al., 2019); or case studies on specific technologies (e.g., Alexander, 2003; Priyono et al., 2020),

[4] We use the term "technology assimilation" to cover different terms used in the studies (e.g., technological innovation, technology adoption), given the literature fragmentation. The term was chosen due to its comprehensiveness and for consistency purposes.

[5] We use the term "technological transformation" analogous to the term "digital transformation" used in business studies to refer to a comprehensive transformation in the organization due to new technology (e.g., Warner & Wäger, 2019; Singh et al., 2020).

which limits the generalizability of their results. Even the individual streams of BMI (Pucihar et al., 2019; Gatautis et al., 2019) and technology assimilation (Ahmad & Siraj, 2018) are not well explored in the SMEs' context.

In recent years, there has been growing scholarly attention on digital transformation (i.e., technological transformation with digital technologies), with recent literature reviews contributing to overall technological transformation literature (e.g., Nadkarni & Prügl, 2021; Vial, 2021). However, although digital transformation studies contribute to the overall body of knowledge on technological transformation, their insights may not be extended to other technological contexts. Moreover, most digital transformation studies overlook SMEs' context (Petzolt et al., 2022).

In fact, technological transformation in SMEs is a research endeavour spread across different research fields and contexts. The literature fragmentation represents a limit for the current scientific literature on technological transformation in SMEs. While SMEs face pressure to introduce different technologies to comply with multiple requirements, this process is encompassing and risky, and existing studies fail to provide its overview. To the best of the authors' knowledge, there is no literature review aiming to improve the general understanding of technological transformation by explicitly combining technology assimilation and BMI in SMEs. Given the SMEs' relevance in terms of employment and the number of firms worldwide (Cantele et al., 2020), research regarding technology transformation in SMEs is needed.

To further establish the technological transformation field, we conducted a systematic literature review (SLR), including 165 peer-reviewed papers. More specifically, the SLR research aims to provide the state-of-the-art of the research field of technological transformation in SMEs, building upon technology assimilation and BMI insights. The SLR draws on descriptive and content analysis. The descriptive analysis presents the development of the study field (from 1999 to 2022). The content analysis inductively assesses the current stage of literature on technological transformation by explicitly merging BMI and technology assimilation concepts. Moreover, we classify the papers' foci into research streams and identify drivers, barriers, enablers, control variables, processes, and outcomes for technological transformation. Finally, we derive a framework for technological transformation based on content analysis.

This work contributes to advancing the understanding of the technological transformation phenomenon in SMEs by shedding light on the existing contributions and future research avenues in the field. As technological transformation is a research endeavour dispersed across different research fields, we contribute to the literature as a first step to make it explicit as a concept and to derive insights into the interactive merger between technology assimilation and

BMI. This chapter is structured as follows. Section 2.2 presents the research design of the SLR. Section 2.3 shows the results of the SLR based on descriptive and content analysis. Section 2.4 shows the discussion of the findings. Finally, sections 2.5 and 2.6 present the perspectives for future studies and conclusions.

2.2. Research design

This study adopted a systematic literature review (SLR) as a research approach to ensure a transparent, structured, and replicable process, reducing bias and enhancing the data analysis's legitimacy (Tranfield et al., 2003). This work followed the SLR phases suggested by Tranfield et al. (2003): (i) review planning, (ii) conducting the review, and (iii) reporting and dissemination.

In the phase of review planning, a literature analysis on technological transformation in SMEs was conducted. This preliminary investigation showed that BMI and technology assimilation are relevant for effective technological transformation, but these concepts are generally separated in literature (i.e., they are not explicitly connected). We identified two literature reviews (Ahmad & Siraj, 2018; Hidayat et al., 2020) focused on factors for technology assimilation and BMI, respectively. Other studies focus on specific aspects of BMI or technology assimilation, such as factors and technology adoption level (e.g., Moeuf et al., 2018). Thus, we identified the need for the SLR because the literature does not provide an overview of technological transformation in SMEs.

In the second phase, the databases Scopus and Web of Science (WOS) were selected because they are the most comprehensive multidisciplinary bibliographic databases (Wang & Waltman, 2016). Moreover, using these databases ensures that any paper retrieved would satisfy four of the quality measure's criteria, i.e., CiteScore, source normalized impact per paper, h-index and SCImago journal rank (Nosratabadi et al., 2019). For the articles' search, the keywords related to SMEs, technology, and BMI presented in Table 1 were combined using the Boolean operator "AND" since the objective is to understand technological transformation in SMEs comprehensively. The papers' search was limited to the English language and peer-review journals since these journals can be considered validated knowledge with the highest impact in the field (Crossan & Apaydin, 2010).

The articles' selection considered the following filters: (i) elimination of duplicates; (ii) reading of title, abstract, and keywords; and (iii) reading of the full text. The use of EndNote® software facilitated the organization of the retrieved papers.

Table 1: Keyword combination

Terms description	Keywords identified for the term
SMEs: According to European Commission (2003), SMEs include three categories of enterprises: (i) micro-enterprises, (ii) small enterprises, and (iii) medium-sized enterprises. The search combined all the terms for these categories using the Boolean operator OR	**SMEs:** "SMEs" OR "SME" OR "small and medium enterprises" OR "small and medium-sized enterprises" OR "small and medium businesses" OR "small and medium-sized businesses" OR "small and medium companies" OR "small and medium-sized companies" OR "micro small and medium enterprises" OR "micro small and medium-sized enterprises" OR "MSME" **Micro-enterprises:** "micro enterpris*" OR "micro-sized enterpris*" OR "micro compan*" OR "micro-sized compan*" OR "micro business*" OR "micro-sized business*" OR "micro firm*" OR "micro-sized firm*" **Small enterprises**: "small enterpris*" OR "small-sized enterpris*" OR "small compan*" OR "small-sized compan*" OR "small business*" OR "small-sized business*" OR "small firm*" OR "small-sized firm*" **Medium-sized enterprises:** "medium enterpris*" OR "medium-sized enterpris*" OR "medium compan*" OR "medium-sized compan*" OR "medium business*" OR "medium-sized business*" OR "medium firm*" OR "medium-sized firm*"
BMI: The term "business model*" was considered to cover the variety of existing words in the field (e.g., business model, business modelling and business model innovation) and terms used by other literature reviews (e.g., Foss & Saebi, 2017)	"Business model*"
Technology: We included all terms related to technology introduction/use	"Technolog*" AND ("assimilation" OR "use" OR "implementation" OR "incorporation" OR "integration" OR "infusion" OR "diffusion" OR "adoption" OR "absorption" OR "usage" OR "routinization" OR "routinisation" OR "innovation" OR "transformation" OR "shift*" OR "change*" OR "introduction")

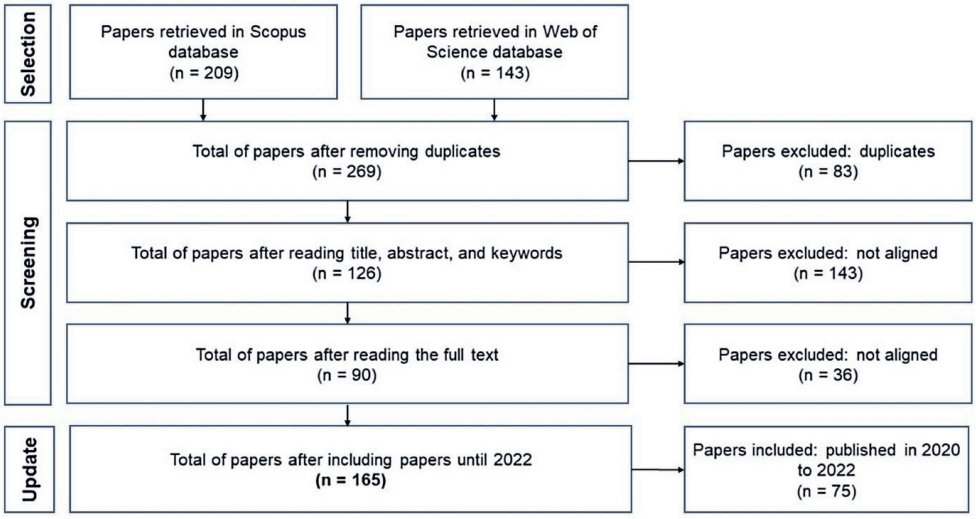
The following criteria were used for screening the articles:

- We discarded papers that do not focus on SMEs' context;
- We are interested in understanding SMEs transforming due to technology introduction/use. Thus, we eliminated papers that present (i) SMEs as technology providers and not as users; (ii) BMI not related to technology; (iii) mention technology-related terms or technology commercialization without addressing technology introduction/use;
- We want to provide an overview of technological transformation by connecting technology assimilation and BMI; thus, we discarded papers that do not address both concepts.

The search for papers was performed in November 2020, and the databases recovered 352 papers (209 from Scopus and 143 from WOS), of which 269 were not duplicates. Using the screening criteria, we read the papers' title, abstract, and keywords (resulting in 126 articles),

followed by reading the full text (resulting in 90 articles). After that, an update was performed (in December of 2022), using the exact keywords and screening criteria limited to 2020 to 2022 years to update until 2022 (resulting in 75 new papers). The selection resulted in 165 articles (Figure 1).

Figure 1: Summary of article selection



The data analysis was conducted through descriptive and content analysis, as Crossan and Apaydin (2010) suggested. We considered categories suggested by Taticchi et al. (2015) for descriptive analysis and included other categories related to our objectives (Table 2).

Table 2: Categories—descriptive analysis (Based on Taticchi et al., 2015)

Category	Object of analysis
Number of publications	Size of the research field
Time distribution of publications	Trends in the research field
Technology type	Technological trends in the research field
Popular journals	Main journals where the research is published
Prolific authors	Leading researchers in the field
Local	Setting of the studies
Research approach	Type of studies conducted

The content analysis categories (Table 3) were defined inductively, i.e., after reading and analyzing the retrieved articles (Mayring, 2021).

Table 3: Categories—content analysis

Category description	References	Note	Section
Conceptualization: Conceptualization of technological transformation and classification of papers' foci	Foss and Saebi (2017); Smajlović et al. (2019)	Similarly to Foss and Saebi (2017), we classify the papers' foci based on technology assimilation and BMI dimensions (process or outcome)	2.3.2.1
Factors: Identification and classification of drivers, barriers, and enablers. Drivers positively influence the decision for innovation. Enablers facilitate the innovation process. Barriers negatively affect innovation decision and processes	Groot et al. (2019); Balocco et al. (2012); Hidayat et al. (2020)	The factors identified were organized using the technology–organization–environment (TOE) framework	2.3.2.2, 2.3.2.3, 2.3.2.4
Process and outcomes: The process (and the interrelatedness) of technology assimilation and BMI and their outcomes are presented	Foss and Saebi (2017); Ahmad and Siraj (2018); Smajlović et al. (2019)	Based on the work of Smajlović et al. (2019), we infer the relationships between technology assimilation and BMI	2.3.2.6, 2.3.2.7, 2.3.2.8
Control variables: The use of controls is common in technology studies, especially when explanatory variables cannot explain data variation	Cruz-Jesus et al. (2019)	–	2.3.2.5
Framework: We organize the factors, processes, control variables and outcomes into a framework	–	–	2.4

Firstly, we classify the papers' foci by connecting the streams of technology assimilation and BMI. Secondly, we identify and classify the influencing factors for technological transformation. These factors are divided into drivers, barriers, and enablers, consonant with BMI and technology assimilation literature. TOE framework was selected for organizing the factors because it is well established in technology assimilation literature (e.g., Hussein et al., 2019; Ahmad & Siraj, 2018) and contains analogous dimensions to internal and external dimensions commonly used in BMI literature (e.g., Foss & Saebi, 2017; Pucihar et al., 2019). For classifying the factor as related to technology assimilation and/or BMI, we used the following criteria: (i) we classify the factors according to the classification used by the paper; (ii) if the study does provide a classification, we do it according to the literature on the streams (Foss & Saebi, 2017; Ahmad & Siraj, 2018). Finally, we inductively build a framework for technological transformation. The results are reported in the next section.

2.3. Results

2.3.1. Descriptive analysis

Regarding the research approach of the papers, most publications are empirical (90%), and the remainder is theoretical. Most empirical studies are qualitative (56%), followed by quantitative studies (41%) and mixed methods (3%). Section 2.3.2.1 of the content analysis details the studies' foci.

Regarding the technology type, most of the papers refer to digital technologies (31%), e-commerce (14%), and industry 4.0 (12%). The publications suggest technological trends over time; for instance, there is a concentration of recent papers on digitalization (45% of the articles published from 2019 to 2022) and industry 4.0 (14% of the papers published from 2018 to 2022). These technological trends align with the fourth industrial revolution that demands SMEs to adopt these technologies. Moreover, the role of digital technologies was emphasized during the COVID-19 crisis since they enabled SMEs to keep their operation running with the new restrictions (Akpan et al. 2021). Another technological trend was identified in the first decade of the 2000s: 75% of the papers published from 2002 to 2009 were focused on e-commerce and e-business.

Regarding the time distribution, most of the 165 papers were published in the last 5 years (2017–2022) (around 80%). Until 2014, the number of publications was not higher than three publications per year. Some possible explanations for the recentness of the papers are: BMI is a relatively recent literature outgrowth (Foss & Saebi. 2017), and studies on technology assimilation and BMI were previously focused on larger enterprises (Popovič et al., 2014; Pucihar et al., 2019).

We found two journals with more than three publications, namely: Sustainability (fifteen publications) and Technological Forecasting and Social Change (five publications). The prevalence of papers in the Sustainability journal suggests the trend of studies discussing how technologies can generate sustainable opportunities and benefits for companies.

Given the multidisciplinarity of the field, we found journals with different scopes with three publications, namely: Journal of Open Innovation: Technology, Market, and Complexity, Industrial Marketing Management, Information Systems Frontiers, Journal of Business Research, Journal of Manufacturing Technology Management, and Journal of Small Business and Entrepreneurship.

The most prolific authors are Julian Müller and Kai-Ingo Voigt (four publications), and their research concerns the 4.0 Industry. Two other research clusters were identified: Harry

Bouwman, Shahrokh Nikou, and Mark de Reuver, that have two publications in common, and their research is part of the European project "Envision", which aims to support SMEs in BMI, and Anis Rozmi, Puteri Nohuddin, Abdul Hadi, Mohd Bakar that have two publications in common regarding ICT technologies. The papers were mainly conducted in Europe (52%), followed by Asia (33%), America (11%), Africa (3%), and Oceania (1%), especially in developed countries.

2.3.2. Content analysis

2.3.2.1. Conceptualization and classification of the papers against the background of technological transformation

Technology assimilation can be defined based on management or system perspectives (Ahmad & Siraj, 2018). According to the management perspective, technology assimilation can be defined as an organizational process in which individuals in an organization have their first contact with a technological innovation, which can lead to the adoption, acceptance, utilization, and institutionalization of the innovation (Ahmad & Siraj, 2018). For example, Zhu et al. (2006) suggest the three phases that an organization follows to assimilate e-business: (i) e-business initiation, (ii) e-business adoption, and (iii) e-business routinization.

According to the system perspective, technology assimilation can be defined as the extent to which technology use diffuses across organizational projects/work processes and becomes part of their activities (Purvis et al., 2001). For instance, Brown and Lockett (2004) present a five-stage "adoption ladder" for e-business, with each stage representing increased complexity: (i) e-mail, (ii) website, (iii) e-commerce (trading online), (iv) e-business (integrated supply chain), and (v) transformed organization (new BMs based on interworking between organizations). In other words, technology assimilation can be discussed as a process or outcome (level of technology assimilation).

Similarly, BMI can be defined as a process (e.g., experimentation, transformation, search) or as an outcome (innovative BM) in which changes are made in a BM's component (e.g., value proposition, customer segments) or the BM's architecture (Foss & Saebi, 2017). BMs are commonly regarded as a representation of the organization's business logic, describing how it creates, delivers, and captures value (Teece, 2010). BMI is less well understood than BMs in literature, and although BMI is increasingly gaining attention, it is still undeveloped, especially in the SMEs' context (Ibarra et al., 2020).

BMI and technology assimilation are interconnected (Smajlović et al., 2019), but the studies generally are not integrative. The papers selected do not comprehensively address technological transformation or present an integrative theoretical background to explain it. Generally, the papers that present a theoretical framework rely on BMI theories and/or technology-related theories (e.g., TOE framework, technology acceptance model, etc.). The studies suggest a link between technology assimilation and BMI, but this connection is indirectly inferred. This observation is in line with one of the most cited papers on the nexus between BMI and technology (Baden-Fuller & Haefliger, 2013) that state that although they are essentially linked with each other, they are separate constructs.

We classify the papers retrieved based on the recurring subjects, the dimensions of technology assimilation and BMI, and the studies' methods, resulting in identifying six main foci[6] (Table 4).

Table 4: Research foci of the papers selected

Research focus	Combination of streams	Method	Examples
1. Description of innovative BMs for certain technologies (12%)	Technology assimilation: Technology per se (technology attributes); and BMI: outcome (configuration)	Conceptual Case studies Qualitative studies	Jutla et al. (1999); Balocco et al. (2012); Holzmann et al. (2017)
2. Process of BMI as a consequence of technology assimilation (13%)	Technology assimilation: Process or technology per se; and BMI: process (actions and changes)	Case studies Qualitative studies	Alexander (2003); Apostolov and Coco (2021); Priyono et al. (2020)
3. Technology assimilation implications in BMI (18%)	Technology assimilation: process or outcome; and BMI: outcome (level of BMI)	Case studies Survey data Qualitative studies Conceptual	Müller et al. (2018); Norris (2020)
4. Factors for technology assimilation and/or BMI (37%)	Technology assimilation: process; and/or BMI: process	Case studies Survey data Qualitative studies	Mujahed et al. (2022); Birkel (2019); Rozmi et al. (2020)
5. BMI as a precursor of technology assimilation (7%)	Technology assimilation: process or technology per se; BMI: outcome (configuration)	Case studies Conceptual Qualitative studies	Chan and Chung (2002); Brown and Locket (2004)
6. Technology assimilation that leads to performance mediated by BMI (13%)	Technology assimilation: outcome (level of technology assimilation); BMI: implications in performance	Survey data Case studies	Bouwman et al. (2018); Pucihar et al. (2019)

[6] We considered the predominant objective/outcomes of the paper, but there are papers that present also results related to other foci (e.g., paper focused on the process that also describe factors).

1. Description of innovative BMs for certain technologies: Papers present new BMs enabled by technologies, which are used as the basis to discuss the new business logic and related processes. The papers' line of reasoning varies according to the nature and recentness of the technologies analyzed. Studies can present criteria to show how certain technologies (and their related BMs) are adequate for SMEs (e.g., Jutla et al., 1999; Laplume et al., 2016). For instance, based on the BM, Laplume et al. (2016) estimate the costs and return on investment (ROI) of additive manufacturing. Some papers present new BMs for new technologies in a particular industry (e.g., Prause, 2015, 2016; Leelasantitham, 2020). For example, Prause (2016) discusses how e-services for industry 4.0 might look and the complementarity of industry 4.0 and e-residency concepts considering the needs of internationally operating SMEs. Some papers present new opportunities enabled by technologies uncovered by BMs. For instance, Holzmann et al. (2017) present business opportunities (and their related BMs) in 3D printing and classify them according to their attractiveness (costs and potential consumers). Thus, BMs can support decision-making on adopting new technology since it can provide insight into what is feasible for SMEs.

2. Process of BMI as a consequence of technology assimilation: The papers describe case studies in which SMEs assimilated new technologies and changed their BM accordingly (e.g., Alexander, 2003; Bourdon & Jaouen, 2016). Some studies provide details in terms of technology assimilation and BMI. For example, Alexander (2003) describes the transition of a small business in the tourism industry for e-commerce, including the technology assimilation actions (e.g., acquisition of new equipment, provider support, personnel changes) and BMI actions (e.g., changes in value proposition, customer relationships and activities). Other papers describe the BMI side of technological transformation (e.g., Liao, 2004; Arnaiz et al., 2016; Sahebalzamani et al., 2022). Few papers provide transformation paths (i.e., how SMEs approach the technological transformation process and the strategies used to cope with its barriers), such as Priyono et al. (2020), that present three digital transformation paths for SMEs. More recent papers address aspects related to decision-making and planning of the technological transformation process. Rozmi et al. (2021) and Azevedo and Almeida (2021) translate the requirements and implications of the transformation process into training programs for decision-makers. Trstenjak et al. (2022) and Petzolt et al. (2022) assess SMEs' readiness and maturity levels.

3. Technology assimilation implications in BMI: The studies describe the changes in BMs as a consequence of technology assimilation. These changes can be in BM elements, such as (i) value elements: value creation, value capture, and value offer; or (ii) building blocks: key

resources, channels, customer segments, key partners, key activities, customer relations, revenue streams, cost structure, value proposition (e.g., Müller et al., 2018; Norris, 2020). Alternatively, changes can be in terms of resulting BMs, such as efficiency-centred and novelty-centred BMs (e.g., Loon & Chik, 2019) or a combination of elements of both (Thomson, 2022). Studies also analyze the extent to which technologies affected the SMEs' BMs (e.g., Moeuf et al., 2018). In 2022, there is a trend of papers describing the COVID-19 crisis as a precursor of technology adoption and how this context has impacted SMEs' BMs (e.g., Musa et al., 2022; Ludin et al., 2022; Khurana et al., 2022). Finally, one paper predicts the expected changes (through scenarios) with industry 4.0 (Bootz et al., 2022).

4. Factors that influence technology assimilation and/or BMI: This is the most popular topic covered by the papers. Papers with this focus describe factors that influence BMI (e.g., Ibarra et al., 2020) and/or technology assimilation (e.g., Mohapatra & Takurta, 2019) in the context of technological transformation. The papers describe barriers, drivers, enablers, managerial approaches, and capabilities for technology assimilation and/or BMI (e.g., Groot et al., 2019).

5. BMI as a precursor of technology assimilation: The studies discuss BMI as a way to enable SMEs to acquire/use technologies that were not previously feasible. This discussion can take the perspective of (i) technology providers or (ii) users. In the first case, technology providers promote changes in their BMs to offer technology feasibly by changing their value capture (e.g., pay-per-use, license, contracts). For example, Olson et al. (2018) discuss how technology providers offer new ways of delivering ERP software for SMEs. In the second case, SMEs can share resources/installations or engage in ecosystems/collaborative arrangements facilitated by a trusted party (e.g., Brown & Locket, 2004; Yang et al., 2019).

6. Technology assimilation that leads to performance mediated by BMI: Papers examine whether technology assimilation or technology-driven BMI leads to superior performance. For example, Chen and Zhang (2015) study how e-commerce influences sales growth. Pucihar et al. (2019) investigated performance outcomes of BMI (including technology-driven BMI) in SMEs. The studies within this category are mainly surveys, except for some case studies. For example, Pfister and Lehmann (2022) conducted a qualitative study examining how SMEs use digital technologies to add value and generate ROI. This category is relatively recent within the papers analysed: most studies were published between 2021 and 2022 (80%).

2.3.2.2. Drivers of technological transformation

The decision to engage in technological transformation can be driven by organizational, environmental, or technological factors or their combination (Müller et al., 2018; Rozmi et al., 2020; Gatautis et al., 2019). Table 5 presents the drivers identified in the papers analyzed and their classification—if they relate to technological assimilation (referred to as TA), BMI, or both.

Table 5: Drivers of technological transformation

Technological drivers	**Description**	**References**	**Classification**	
			TA	**BMI**
Relative advantage	The advantage expected of adopting technology in an organization compared to not adopting it [1]	[1–15]	X	
Perceived usefulness	The degree to which owners/managers believe that employing a technology would improve organization performance [1]	[1, 4, 8, 12, 16–20]	X	
Ease of use	The degree to which an individual believes technology use would be free of effort [18]	[5, 8, 16, 18–21]	X	
Compatibility	The extent to which a technology is appropriate with technology infrastructure, culture, values, and work practices [22]	[5, 17, 20]	X	
Technology readiness	Technology readiness comprises the organization's technology infrastructure, compatible systems, and employee technical skills [22]	[4, 5, 12, 23]	X	
Environmental drivers	**Description**	**References**	**Classification**	
			TA	**BMI**
Support of a trusted party	The support of a trusted party provides confidence for SMEs to engage in technological transformation	[2–4, 7, 10, 12, 24–27]	X	X
Existence of feasible BM for SMEs	SMEs have limitations that need to be considered to make it feasible for them to adopt new technologies	[6, 7, 26–30]		X
Competitive pressure	Moves of competitors influence the decision on innovation activities [3]	[2–4, 12, 14, 17, 31–33]	X	X
Customer and/or supplier pressure	Customer and/or supplier request some standards of SMEs related to the use of technologies (e.g., standardized data exchanged) [3]	[2–5, 9, 17, 25, 33–35]	X	X
Government regulations	Policy regulations drive the adoption of new technology (e.g., determination of new standards that can be achieved with new technology)	[7, 14, 16, 17, 36]	X	

Continuation of Table 5: Drivers of technological transformation

Environmental drivers	Description	References	Classification	
			TA	BMI
Disruptions	Disruptions in the supply chain (e.g. the COVID-19 crisis) push SMEs to adopt technologies and change their BM to cope with them	[12–14, 28, 36–45]	X	X
Technology turbulence	Rate of technological advancement within an industry influence the decision to change the BM [46]	[46–48]		X
Organizational drivers	**Description**	**References**	**Classification**	
			TA	**BMI**
Top management support	Support of owner/manager in introducing new technology and/or changing the business	[1, 4, 10, 12, 49–51]	X	X
Perception of market opportunities or changes	SMEs proactively conduct technological transformation to attend to perceived market opportunities or changes	[14, 35, 49, 52]	X	X
Strategic orientation	Orientation towards strategic decisions enables the implementation of technology into BMs	[5, 47, 48, 53]	X	X
Innovation activities	A company undertakes activities to add value to its products and services	[32, 47, 48]		X

References: [1] Hussein et al. (2019); [2] Pavic et al. (2007); [3] Gatautis and Vitkauskaite (2009); [4] O'Reilly and Ugray (2010); [5] Gayen et al. (2016); [6] Moeuf et al. (2018); [7] Groot et al. (2019); [8] Mohapatra and (2019); [9] Apostolov and Coco (2021); [10] Mujahed et al. (2022); [11] Kraft et al. (2021); [12] Hussain et al. (2021); [13] Akpan et al. (2022); [14] Ludin et al. (2022); [15] Saáry et al. (2022); [16] Bracci et al. (2022); [17] Cinjarevic et al. (2021); [18] Lim and Baharudin (2013); [19] Nichifor et al. (2022); [20] Chen et al. (2018); [21] Cranmer et al. (2021); [22] Ahmad et al. (2018); [23] Chonsawat and Sopadang (2020); [24] Yang et al. (2019); [25] Norris (2020); [26] Kim et al. (2008); [27] Brown and Lockett (2004); [28] Gregurec et al. (2021); [29] Jutla et al. (1999); [30] Chan and Chung (2002); [31] Zhang et al. (2015); [32] Pucihar et al. (2019); [33] Yang et al. (2022); [34] O'Toole (2003); [35] Müller et al. (2018); [36] Subriadi and Wardhani (2022); [37] Priyono et al. (2020); [38] Akpan et al. (2021); [39] Paoloni et al. (2022); [40] Giotopoulos et al. (2022); [41] Ragazou et al. (2022); [42] Lu et al. (2022); [43] Khurana et al. (2022); [44] Zamani et al. (2022); [45] Musa et al. (2022); [46] Molina-Castillo et al. (2022); [47] Gatautis et al. (2019); [48] Bouwman et al. (2018); [49] Alexander et al. (2003); [50] Garzella et al. (2020); [51] Müller et al. (2021); [52] Loon and Chik (2019); [53] Yousaf et al. (2021)

Regarding technological drivers, the relative advantage (also referred to as potential/perceived benefits) is one driver often cited in the literature. Some relative advantages expected by SMEs are cost reduction, operational efficiency, and increased sales. Moreover, recent studies claim that technologies may positively impact sustainability; for instance, digital technologies may enable improvements in carbon emissions, material consumption, and waste reduction (Saáry et al., 2022). From the papers analyzed, most of the benefits mentioned are potential (i.e., not empirically confirmed by the studies).

As researchers define relative advantage differently, relative advantage and perceived usefulness are often used interchangeably in literature (Hussain et al., 2021). Perceived

usefulness is also related to the benefits expected but focused on enhancing job performance (Hussein et al., 2019), while relative advantage is a broader concept. Ease of use is also a technological driver, which is expected since SMEs generally do not adopt complex systems (Brown & Lockett, 2004).

SMEs' technological structure and previous experience also impact the decision to adopt technology: the greater the compatibility between enterprise policy and technology, the greater the likelihood of adopting the new technology (Cinjarevic et al., 2021). Moreover, as SMEs lack financial and technological resources, technology readiness is also a predictor of technology adoption (Gayen et al., 2016) since adopting certain technologies requires infrastructure and skills (Hussain et al., 2021).

Regarding environmental drivers, the support of a trusted party is often mentioned as a driver for SMEs to engage in technology assimilation and/or BMI since cooperation with entities is seen as a way to mitigate the risks related to innovation (Yang et al., 2019; Brown & Lockett, 2004). Trusted parties can be technology providers, government, cooperatives, industry associations, or private or public institutions.

Studies emphasize the role of technology providers as a relevant trusted parties supporting technological transformation in SMEs. Several papers consider the provider perspective or provider support aspects central in their studies (e.g., Groot et al., 2019; Kim et al., 2008; Mohapatra & Thakurta, 2019). According to Kim et al. (2008), some of the reasons for using a technology provider are: (i) predictable costs; (ii) guaranteed performance levels; (iii) Free up staff to focus on internal issues; (iv) providers have expertise; (v) quicker implementation; (vi) Automatic upgrades; (vii) Guaranteed uptime; (viii) Lack of internal resources; (ix) Security concerns; (x) Try out the technology before buying.

The existence of feasible BM for technologies is discussed in the literature based on the user or provider perspectives. For users, feasible BMs support the decision to adopt technology in SMEs (Jutla et al., 1999). For providers, the perception of new opportunities supports in creation of new value propositions that meet SMEs' needs. For example, Groot et al. (2019) state that the limited time window of Climate Smart Agricultural (CSA) technologies constrains SMEs' technology adoption. In this regard, the authors suggest that a concrete action to mitigate this constraint would be leasing machinery in other districts. Moeuf et al. (2018) provide another example of a barrier related to technological characteristics: some industry 4.0 technologies are expensive with a long return on investment, and new BMs for SMEs are required.

Competitive pressure is related to the industry sectors in that SMEs are operating (Gatautis & Vitkauskaite, 2009), and those SMEs that operate in a competitive environment are more likely to adopt new technologies (Hussain et al., 2021) and change their BM (Pucihar et al., 2019). SMEs' customers and/or suppliers can exert external pressure to adopt a particular technology, given contracts with specific customers (Apostolov & Coco, 2021) and pressure from larger partners (O'Toole, 2003).

Government regulations can also drive technology adoption (directly or indirectly). For example, Groot et al. (2019) state that the Punjab government began enforcing the ban on burning rice and wheat stubble in farmlands, which can drive the adoption of CSA technologies. Another environmental factor that drove technological transformation in SMEs is disruptions, such as the COVID-19 crisis, which have received increasing academic attention within the last 2 years (e.g., Song et al., 2022; Musa et al., 2022; Akpan et al., 2022). In this context, technology was a survival source during the pandemic, as companies adopted digital technologies to maintain their operations (Akpan et al., 2021; Priyono et al., 2020). Technology turbulence is an environmental driver related to rapid technological development within an industry that motivates to engage in BMI (Bouwman et al., 2018).

Organizational drivers are mainly related to top management actions and vision. Firstly, top management can provide support and pursue strategic orientation toward technological transformation. SMEs can also be internally motivated to adopt technologies when the owner/manager perceives market opportunities or changes in the market (e.g., changes in consumer behavior) that new technology can address (Alexander, 2003; Ludin et al., 2022). According to Müller et al. (2018), whether the company is internally motivated and/or externally pressured towards adopting new technology impacts which BM elements are innovated. Finally, the conduction of innovation activities can also play a role in decisions related to BMI, such as technology adoption.

2.3.2.3. Barriers to technological transformation

The barriers to technological transformation can be related to its decision (i.e., the decision to adopt a technology or change the BM by using a technology) or its process (i.e., transforming the business to exploit new technology). Indeed, the barriers vary according to the stage of technology assimilation (Gatautis & Vitkauskaite, 2009) and BMI (Santa-Maria et al., 2022), consequently varying according to the stage of technological transformation. The barriers identified are shown in Table 6.

Concerning technological barriers, security concerns relate to data-driven technologies (e.g., ICT) and are considered a barrier to adoption (Mohapatra & Thakurta, 2019) and to the intention to continue using the technology (Hussein et al., 2019). SMEs are concerned about risks associated with new technologies, such as keeping privacy and confidential corporate data (Mohapatra & Thakurta, 2019), transaction security (Gatautis & Vitkauskaite, 2009), and losing data. Indeed, data and information are some of the most valuable assets for companies (Lim & Baharudin, 2013).

The high cost is also a barrier to adopting and evolving the technology assimilation process. SMEs have limited possibility to invest in technologies; thus, their decision is significantly influenced by cost. Two studies have shown the preference of SMEs to adopting cheaper technologies: (i) Moeuf et al. (2018) concluded in their literature review that SMEs exploit low-cost technologies of industry 4.0; (ii) Mohapatra and Thakurta (2019) concluded through a survey with Indian SMEs that the pricing tariff is the most important factor in choosing a cloud computing provider.

SMEs generally do not adopt complex systems (Brown & Lockett, 2004; Rozmi et al., 2020). For instance, Brown and Lockett (2004) state that SMEs appear comfortable with low-complexity applications (e-mail) but present limited or no engagement with high-complexity applications (e-marketplaces). According to the authors, SMEs would not adopt complex applications without substantial support. Another technological barrier is the difficulty of ensuring the technology interoperability with existing systems (Gatautis & Vitkauskaite, 2009) within and between companies.

Three environmental barriers are related to institutional context: poor socio-economic situation, unfavorable regulatory landscape, and lack of access to finance. Poor-socio economic situation is an unfavorable local context primarily related to developing countries, which are not on par with developed countries. Developing countries face additional challenges regarding technological transformation, which may be linked to the low level of internet penetration, dysfunctional educational systems, poor infrastructure and malfunctioning political and economic systems (Akpan et al., 2022).

The unfavorable regulatory landscape restricts technological transformation due to: policies that do not attach importance or urgency to technologies (Rozmi et al., 2020), lack of government support (Indrawati et al., 2020), differences in legal and regulatory environments in cross-border transactions (Gatautis & Vitkauskaite, 2009), and lack of regulation for new technology (Bracci et al., 2022). For example, recent studies show how the lack of regulation hampers the use of blockchain technologies (Alshareef & Tunio, 2022; Juszczyk & Shahzad,

2022). Moreover, SMEs can be challenged by the lack of access to finance, especially for new organizations (Alshareef & Tunio, 2022). Access to finance can be challenging due to long and arduous application processes, existing subsidies that do not match SMEs' reality (Groot et al., 2019), or predatory lending (Akpan et al., 2021).

Problems in partnerships can be in terms of (i) lack of partners, (ii) behavior of partners, and (iii) relationship management. According to Kollmann and Häsel (2008), alliances, in general, can present severe conflict and opportunism during the entire collaboration time because integrating different BMs is inherently risky. Still, according to the authors, the risks are related to partner identification and subsequent project execution. Companies need to understand (i) if the collaboration is strategic and (ii) if the organizational structure and company culture of partners fit (Kollmann & Häsel, 2008).

Certain technologies and BMI require collaboration to leverage benefits and fulfil functions; thus, partnership problems may be even more problematic for those cases. For example, Reim et al. (2022) identified three BMI challenges (in the case of internationalization) related to partnerships: (i) difficulties in identifying, attracting, and engaging with international partners, (ii) lack of suitable international partners, and (iii) difficulties in building trust with partners. Another example is blockchain technology which requires a solid and extensive network to enable SMEs to fully capitalize on its advantages (Alshareef & Tunio, 2022).

The lack of customer acceptance/demand is an external resistance to the technology use or related products and/or services. For example, Coreynen et al. (2017) describe the product-service systems offerings, which present a cultural shift for customers (e.g., not owning products), which can lead to a nonacceptance. Reim et al. (2022) identify different challenges related to customer acceptance in the case of internationalization, such as lack of suitable customers, limited market information, challenging market and visibility with foreign customers, new customer acquisition, and fluctuation in demand. Moreover, SMEs present difficulties in producing new offerings (Coreynen et al., 2017) and commercializing technology products (Shin, 2017). In fact, SMEs may face difficulties in creating new value propositions and also in delivering and capturing value from technological transformation (Reim et al., 2022).

Regarding organizational barriers, the knowledge and perception of the owner manager play a central role in decisions of technological transformation. The owner-manager can be unaware of new technologies available (Azevedo & Almeida, 2021), leading to non-adoption. The owner-manager perception affects their intention to adopt technology, and previous bad

experiences with technology or mistrust (especially for new technologies that do not present clear evidence of their benefits, with uncertain profitability) also represent an adoption barrier. If not from a technology background, the owner-manager may be unaware of how to exploit a technology (O'Toole, 2003) or how to do BMI (e.g., process and techniques). Another difficulty managers face is taking responsibility for the changes (Yang et al., 2019) or understanding the changes required by new technology. SMEs generally do not possess highly skilled workers, and depending on the level of expertise required, it can be challenging to hire qualified workers due to the scarcity of these professionals and the limited career prospects offered by SMEs (Birkel et al., 2019). Therefore, finding and retaining those professionals can be challenging for SMEs (Lu et al., 2022). For example, Birkel et al. (2019) state that industry 4.0-related technologies will need hiring specialists with unique skills (e.g., computer science, programming, data security), which is challenging for SMEs because these specialists are scant, and SMEs cannot afford them in many cases.

SMEs' employees may also resist changes imposed by new technology due to a lack of specific technical knowledge, difficulty adapting, fear of job loss, or loss of recognition/responsibilities (Birkel et al., 2019). According to Bourdon and Jaouen (2016), changing employees' resistance can be easily managed in large companies, but in SMEs, there is a magnification effect; the relative impact of an individual is multiplied (one employee out of ten means that 10% of workforce resists change). The employees may also not be committed to change due to additional workloads required, as reported by one of the case studies of Teoh et al. (2022) of an SME that adopted digital BMI.

SMEs are characterized by a lack of resources such as financial, time, and competence (Sell et al., 2019). Given this context, SMEs are more conservative and aversive to risks and can also have a short-term vision. When short-term benefits do not appear, a "wait-and-see" attitude appears to prevail, which may be attributed to an absence of strategic planning (O'Toole, 2003). The lack of resources restricts BMI (Reim et al., 2022) and technology assimilation (Mohapatra & Thakurta, 2019), restricting the pace of technological transformation in SMEs. The lack of resources also implies difficulties in entering new markets (Yang et al., 2019).

The difficulty in implementing changes in the current BM is also an organizational barrier. For example, Alexander (2003) states that larger firms would expect to have an easier time moving to e-commerce since they have a more departmentalized infrastructure, and management functions would not include dealing with day-to-day operations, marketing, supplier relationships, and contract negotiations. Moreover, SMEs may also be stuck in the "old way of

doing things" (Pavic et al. 2007) or that existing BM is incompatible with the new structures (Kumar et al., 2022).

Finally, SMEs generally depend on external expertise for most of the technical expertise (O'Toole, 2003). Alexander (2003) describes the case of a small company transitioning to e-commerce that was first dependent on the technology providers and after the owner-manager developed expertise in-house. Priyono et al. (2020) also mentioned a case in which the company relied on partners for its digital functions. The authors state that this is a temporary solution, and for sustainable competitive advantage, they need to develop digital capability in-house.

Table 6: Barriers to technological transformation

Technological barriers	**Description**	**References**	**Classification**	
			TA	**BMI**
Security concerns	Technology needs to accomplish security aspects, such as confidentiality and data privacy [1]	[1–19]	X	
High cost	Technology costs can include installation, training, upgrading, and hiring people	[1–6, 8, 11, 17, 20–30]	X	
Complexity	SMEs have difficulties in mastering the complexities of some technologies [15]	[2, 11, 15, 18, 20, 31]	X	
Interoperability/ Integration	Ensuring technology interoperability/integration with existing systems, standards, and interfaces within and across companies [6]	[3–7, 11, 15, 16, 32]	X	
Environmental barriers	**Description**	**References**	**Classification**	
			TA	**BMI**
Poor socio-economic situation	Context characterized by poor education, infrastructure, and lack of government support [35]	[25, 29, 33–36]	X	X
Unfavorable regulatory landscape	Policies that do not attach importance, urgency, or present bureaucracy to innovations	[2, 6, 12, 13, 16, 17, 28, 29, 36, 37]	X	X
Lack of access to finance	Difficulties in accessing finance or financial support do not match SMEs' needs	[12, 17, 22, 28, 29, 36, 37]	X	X
Problems in partnerships	Lack of business partners or partners' problematic behaviors. Complexities in managing partnerships	[6, 18, 28, 29, 37–41]	X	X
Lack of customer acceptance/demand	Lack of customer acceptance/demand regarding technology use or its related products/services	[3, 15, 28, 41–45]	X	X

Continuation of Table 6: Barriers to technological transformation

Organizational barriers	Description	References	Classification	
			TA	BMI
Lack of awareness concerning technology	SMEs can be unaware of new technologies	[1, 3, 6, 11, 17, 46, 47]	X	
Lack of awareness concerning BMI	Unawareness about BMI, how to do it, and BM related to specific technologies [48]	[5, 6, 15, 19, 30, 46, 48, 49]		X
Lack of resources	Lack of resources in terms of people, time, and finances	[5, 6, 11, 17–19, 24, 26, 37, 42, 50–52]	X	X
Lack of skilled workers Difficulty in hiring skilled workers	SMEs usually do not have skilled workers and face difficulties in hiring or finding skilled workers	[2, 8, 15, 17, 18, 22, 28, 29, 36, 42, 48, 53, 54]	X	
Mistrust	Mistrust that a particular technology will provide benefits	[6, 11]	X	
Resistance to change	Employees resist using technology and changing their ways of working	[3, 15, 17–19, 29, 32, 42]	X	X
SMEs' conservative profile	SMEs are more reactive than proactive in innovating	[5, 6, 8, 29]	X	X
Lack of strategy	Lack of strategy and planning leads to difficulties in achieving the potential benefits of technology	[5, 39, 50, 54, 55]	X	X
Lack of skills	Lack of skills to manage the technology assimilation and/or business transformation	[3, 6, 11, 28–30, 32, 39, 41, 42, 48, 55, 56]	X	X
Difficulty in implementing changes in the current BM	Difficulties in balancing the current BM with new BM practices when engaging in business transformation	[2, 6, 11, 17, 55, 57, 58]		X
Challenges for creating, delivering, and capturing value	Difficulties in deploying innovative products or services related to a technology effectively. The difficulties can also be in terms of delivery and capture of the new value proposition	[39, 41, 54, 59, 60]		X
Previous bad experiences with technology	Previous bad experiences with technology inhibit the intention to adopt and use new technologies	[2, 11]	X	
Dependency on external expertise	SMEs depend on external parties (e.g. technology providers) to acquire knowledge and skills	[42, 61]	X	
Difficulty in entering the market	Big players dominate markets	[25, 39, 60]		X
Leadership issues	The managers are unwilling to be responsible for technology assimilation or BMI or lack understanding of the required actions	[11, 51, 60]	X	X
Short term vision	SMEs generally have a short-term orientation, and the benefits of technologies may take time	[5, 62]		X

References: [1] Mohapatra and Thakurta (2019); [2] Rozmi et al. (2020); [3] Westerlund (2020); [4] Venkatachalam et al. (2014); [5] O'Toole (2003); [6] Gatautis and Vitkauskaite (2009); [7] Jhang and Chang (2017); [8] Lim and Baharudin (2013); [9] Hussein et al. (2019); [10] Karunagaran et al. (2019); [11] Pavic et al. (2007); [12] Akpan et al. (2021); [13] Bracci et al. (2022); [14] Gavrila and Ancillo (2021); [15] Birkel et al. (2019); [16] Juszczyk and Shahzad (2022); [17] Kumar et al (2022); [18] Lu et al. (2022); [19] Pfister and Lehmann (2022); [20] Moeuf et al. (2018); [21] Cranmer et al. (2021); [22] Ingaldi and Ulewicz (2020); [23] Hao et al. (2018); [24] Kim et al. (2008); [25] Mkansi et al. (2019); [26] Chan and Chung (2002); [27] Pomffyová et al. (2017); [28] Fanelli (2021); [29] Indrawati et al. (2020); [30] Musa et al. (2022); [31] Brown and Lockett (2004); [32] Teoh et al. (2022); [33] Hussain et al. (2021); [34] Mujahed et al. (2022); [35] Akpan et al. (2022); [36] Groot et al. (2019); [37] Alshareef and Tunio (2022); [38] Kollmann and Häsel (2008); [39] Apostolov and Coco (2021); [40] Bootz et al. (2022); [41] Reim et al. (2022); [42] Bourdon and Jaouen (2016); [43] Coreynen et al. (2017); [44] Huynh (2022); [45] Jutla et al. (1999) [46] Azevedo and Almeida (2021); [47] Nichifor et al. (2022); [48] Ibarra et al. (2020); [49] Chiarvesio et al. (2022); [50] Sell et al. (2019); [51] Brink (2017); [52] Matenga and Mpofu (2022); [53] Norris (2020); [54] Chen and Zhang (2015); [55] Trstenjak et al. (2022); [56] Balocco et al. (2012); [57] Alexander et al. (2003); [58] Loon and Chik (2019); [59] Shin (2017); [60] Yang et al. (2019); [61] Priyono et al. (2020); [62] Isensee et al. (2020)

2.3.2.4. Enablers to technological transformation

The summary of enablers identified in the literature is presented in Table 7. Interestingly, all the enablers identified can be applied to BMI and technology assimilation.

Table 7: Enablers for technological transformation

Organizational enablers	**Description**	**References**	**Classification**	
			TA	**BMI**
Top management support	Top management creates a supportive innovation environment and provides the required resources for TA and BMI	[1–7]	X	X
Commitment of resources/investments	Commitment of resources entailing budgets, human capabilities, and time for innovation	[1, 4, 7–13]	X	X
Organizational culture favorable to technological transformation	Shared values, ideologies, philosophies, assumptions, beliefs, expectations, attitudes, and norms determine people's behavior [15]	[3, 8, 14–16]	X	X
Companies' capabilities	Different capabilities are required for technological transformation, such as dynamic capabilities, networking, managerial, and technological capabilities	[3, 6, 10, 12–31]	X	X
Strategic alignment	Strategic alignment of business strategy and technology strategy	[3, 4, 7, 14, 24, 32–34]	X	X
Environmental enablers	**Description**	**References**	**Classification**	
			TA	**BMI**
Partnerships	SMEs need to collaborate with other organizations for different purposes, such as accomplishing activities in the supply chain, acquiring technologies, equipment or skills, funding, and collaborating in product development and innovation	[4, 10, 12, 14, 20, 27, 33, 35–37]	X	X
Support of a trusted party	External support of trusted parties for conducting innovation activities	[7, 38–44]	X	X

References: [1] Alexander et al. (2003); [2] Hussein et al. (2019); [3] Ibarra et al. (2020); [4] O'Toole (2003); [5] Müller et al. (2021); [6] Garzella et al. (2020); [7] Teoh et al. (2022); [8] Bouwman et al. (2019); [9] Moeuf et al. (2018); [10] Apostolov and Coco (2021); [11] Chen and Zhang (2015); [12] Westerlund (2020); [13] Paiola et al. (2022); [14] Priyono et al. (2020); [15] Isensee et al. (2020); [16] Khattak (2022); [17] Xie et al. (2022); [18] Song et al. (2022); [19] Kim et al. (2018); [20] Kollmann and Häsel (2008); [21] Liu et al. (2021); [22] Loon and Chik (2019); [23] Rozmi et al. (2020); [24] Soluk and Kammerlander (2021); [25] Tali et al. (2021); [26] Vrontis et al. (2021); [27] Kassim et al (2016); [28] Fanelli (2021); [29] Gerlitz (2016); [30] Herve et al. (2020); [31] Coreynen et al. (2017); [32] Chen et al. (2018); [33] Chan and Chung (2002); [34] Pfister and Lehmann (2022); [35] Wu et al. (2022); [36] Gutierrez-Leefmans and Holland (2019); [37] Mkansi et al. (2019); [38] Venkatachalam et al. (2014); [39] Groot et al. (2019); [40] Brown and Lockett (2004); [41] Balocco et al. (2012); [42] Gatautis and Vitkauskaite (2009); [43] Yang et al (2019); [44] Huynh (2022)

Top management plays an essential role in creating the conditions for technological transformation since they act on (i) the definition of innovation strategy; (ii) the commitment of resources for technological transformation; (iii) the culture towards technological transformation; and (iv) alignment of operational and strategic actions. The innovation strategy needs to encompass the conditions for using the technology and change the business (activities, value proposition, partnerships, the balance of revenue and cost) according to marketing opportunities. Top management should provide guidance, supervision, and training, especially in the first moment of technology introduction, to ensure that the employees can operate with new technology and do not commit repetitive mistakes (Teoh et al., 2022).

SMEs need to consider strategies for: acquiring knowledge and resources regarding the new technology (Groot et al., 2019; Apostolov & Coco, 2021); value creation according to the technology (Chan & Chung, 2002; Coreynen et al., 2017); technology alignment, i.e., vision, objective, structures (Venkatachalam et al., 2014); enable functions to deliver value, e.g., co-design with customers, integrating distribution channels, outsource weaker functions (Chan & Chung, 2002); and enable value proposition and revenue model (Gutierrez-Leefmans & Holland, 2019).

In general, partnerships are often part of SMEs' strategy for technological transformation, given their lack of resources. These partnerships can be for acquiring new technology and knowledge; for example, cooperatives offer relatively cheap loans for renting and/or purchasing technology (Groot et al., 2019). Partnerships can be aimed at satisfying niche markets together; for instance, a company's R&D can collaborate with a partner's manufacturing department to develop a new product and manufacture it cheaply (Chan & Chung, 2002). Other examples are companies with no global entry experience that partner with experienced global market players (Shin, 2017).

External collaboration can include (i) partnerships among companies to accomplish business functions within the value chain or (ii) external support. In the first case, connecting ecosystem partners entails risks such as interdependence and coordination challenges, necessitating BMs' alignment with the value network and strategic risk management (Birkel et al., 2019). External

support involves parties such as the government, technology providers, and universities supporting innovation activities. According to Venkatachalam et al. (2014), the scope of provider support can go beyond adoption and implementation challenges, including technology orientation, operation alignment, and strategic alignment. The SMEs can also collaborate with customers to better address their needs (Westerlund, 2020; Coreynen et al., 2017).

Resource allocation is critical for technological transformation (Chen & Zhang, 2015; Westerlund, 2020). In this regard, although studies state that investments in technology assimilation and BMI have a positive impact on technological transformation success (Alexander, 2003; Bouwman et al., 2019; Chen & Zhang, 2015), few practical orientations are given on how to decide on those investments given SMEs' lack of resources.

The owner/manager's actions influence the culture towards technological transformation in SMEs. In this regard, their actions need to create a positive environment for technological transformation, which include training in the new way of doing things and accepting the new technology. According to Chen et al. (2018), technology, people, and organization must be appropriately aligned to benefit from technology.

Finally, the success of the technological transformation is also shaped by the companies' capabilities (e.g., technological, managerial, network, and dynamic capabilities), which depend on their context. In this regard, SMEs can achieve outcomes by combining different capabilities (Priyono et al., 2020; Ibarra et al., 2020).

2.3.2.5. Control variables—Size, age, industry, and technology type

Papers consider industry sector (Del Giudice et al., 2021; Qu et al., 2021), age (Wang et al., 2020; Denicolai et al., 2021), and size (Wang et al., 2020; Denicolai et al., 2021) as control variables. The industry sector influences the innovation and competitive conditions in the environment (Del Giudice et al., 2021), influencing the technologies adopted and BMI practices. Moreover, the age of a company influences acquired tangible and intangible resources (Del Giudice et al., 2021), influencing technological transformation practices. For example, the BMI phenomena in established firms differ substantially from newly created companies (Ibarra et al., 2020). Authors also claim that the older the SME, the less likely it will adopt certain technologies (Pavic et al., 2007; Rozmi et al., 2020).

Company size influences the company's resources, determining the possibilities for SMEs to adopt technologies and the paths for transformation. In this regard, technologies recognized as "new" for SMEs can be standard for larger companies, and technologies that are feasible for medium companies may not be feasible for small ones (Olson, 2018). Finally, technology type

also influences technological transformation since technological characteristics play a role in the level of BMI changes (incremental or radical) (Bouwman et al., 2018; Leelasantitham, 2020; Lokshina et al., 2018). For example, Bouwman et al. (2018) concluded that social media and big data affect BMI differently. According to the authors, big data has a broader impact than social media because social media usage is more focused on channels, whereas big data can affect companies in all of their core activities as well as the activities of their key partners.

2.3.2.6. Process of technological transformation

Few papers focus on the process of technological transformation by describing SMEs that successfully transformed or intend to transform (e.g., Alexander, 2003; Liao, 2004), and the studies fail to provide details about SMEs that have discontinued technology use or failed in technological transformation. The case studies focus on the actions and changes made during the transformation process but generally do not describe the phases or tools for technology assimilation, BMI, or technological transformation. Exception for the longitudinal case study conducted by Paiola et al. (2022) regarding the process of IoT-driven BMI. The authors state that the process is incremental and delimitate the phases of BMI: inception, experimentation, and replication. However, a model combining technology assimilation and BMI is still lacking. Few studies present more insights into the transformation process by presenting paths (e.g., Coreynen et al., 2017; Shin, 2017; Priyono et al., 2020; Teoh et al., 2022).

These studies analyze the current companies' resources and capabilities, the barriers to technological transformation, and the strategies to overcome these barriers. For example, Priyono (2020) present different case companies which responded differently to digitalization: SMEs with a high level of digital maturity accelerated the transition toward digitalized firms; SMEs with low digital maturity that only digitize their sales functions; and SMEs with low digital literacy that outsource their digital functions to partners. Recent studies propose the evaluation of the current situation of SMEs before transformation by assessing the readiness factor (Trstenjak et al., 2022) and the maturity level (Petzolt et al., 2022). These studies support strategic planning for technological transformation, enabling a better understanding of the transition.

Studies suggest that SMEs without external support and previous knowledge regarding technologies experience a gradual transformation process, such as a step by step (Shin, 2017; Mohapatra & Thakurta, 2019; Müller et al., 2018), adopting technologies in one function of the company (Priyono et al., 2020), or outsourcing (Chan & Chung, 2002). In this sense, outsourcing requires managing the relationship between the firms and partners (Priyono et al.,

2020) while acquiring and integrating knowledge will be shaped by the firms' managerial capacities (Apostolov & Coco, 2021).

Studies suggest the importance of providers in the technological transformation process (e.g., Brown & Lockett, 2004; Groot et al., 2019; Alexander et al., 2003), especially when the technology is complex or the company does not possess the required technical capabilities, with providers also supporting the BMI process (e.g., Venkatachalam et al., 2014; Brown & Lockett, 2004). In this regard, the analysis of the papers suggests an overlap of BMI and technology assimilation, but the papers do not present details on this overlapping or on how to integrate these processes.

2.3.2.7. Interrelatedness between technology assimilation and BMI

Smajlović et al. (2019) indicate two relationships between technology assimilation and BMI: (i) technology assimilation that drives BMI, and (ii) BMI mediates the relationships between technology assimilation and the company's performance, which were also identified in the papers analysed. Firstly, technology assimilation can drive BMI, given its requirements/dynamics (papers on the foci 1, 2, 3, and 4 – Table 4). For example, Priyono (2020) describes SMEs that digitalized the sales function and needed redesigning distribution and sales channels. Alexander (2003) describes a small company that adopted e-commerce and needed to change key activities and resources (e.g., developing IT function, web developer), and customer relationships (before in person and afterwards online). Pucihar et al. (2019) state that new information technologies enable the design of innovative and new BMs, which often disrupt existing industries and markets.

Secondly, papers in focus 6 relate to the second relationship (BMI mediates the relationships between technology assimilation and the company's performance). In this relationship, BMI determines the nature of complementarity between BMs and paths for monetization. This complementarity includes value mechanisms such as value offer (the value embedded in the product/service offered to the customer), value creation (identifying customers and how they are engaged) and value capture (how value is delivered and monetized) (Müller et al., 2018). In sum, BMI connects technology and value by producing products or services that customers will pay for, and selecting the right technology and customer segments is part of BMI's strategy.

Finally, we identified a third relationship BMI as a precursor of technology assimilation (papers in focus 5), which is not commonly addressed in the literature. This relationship is focused on enabling SMEs to acquire/use technologies that were not previously feasible for these

companies. Although this relationship is not often discussed in the literature, it is a topic that makes sense in the SMEs' context, given their lack of resources.

2.3.2.8. Outcomes of technological transformation

The outcomes of technological transformation can be discussed in terms of (i) the level of technology assimilation, (ii) the level of BMI, and (iii) performance outcomes. The level of technology assimilation can be evaluated in terms of the stage of technology assimilation within a company. For example, Fichman and Kemerer (1997) employ a six-stage to classify the level of technology assimilation: (i) awareness, (ii) interest, (iii) evaluation/trial, (iv) commitment, (v) limited deployment, and (vi) general deployment. In the case of digital technologies, authors classify the level of technology assimilation in terms of the extent to which technology adoption has spread in three areas: organization and management, marketing and sales, and production (Moeuf et al., 2018; Sabatini et al., 2022).

The level of BMI refers to the extent to which BM elements have been changed (Sabatini et al., 2022), ranging from a few changes to an entirely new BM. Authors propose different ways to classify the level of BMI based on criteria such as novelty and scope (Foss & Saebi, 2017) or the number of BM elements impacted – also referred as complexity of BMI (Sabatini et al., 2022).

The level of technology assimilation and BMI are connected, and the studies discuss the level of technology assimilation in terms of the extent to which technologies affect SMEs' BMs (Sabatini et al., 2022). For instance, Westerlund (2020) claims that internationally-oriented online SMEs differ from domestically-oriented ones in terms of, among other things, a higher degree of use of information systems. In general, the studies assert that SMEs achieved a low level of technology assimilation and BMI (e.g., Moeuf et al., 2018; Müller et al., 2021; Bracci et al., 2022; Reuschke & Mason 2022; Akpan et al., 2022).

This low transformation level may occur for more recent technologies that SMEs have just started to acquire/use, and these technologies take time to be assimilated by SMEs (Moeuf et al., 2018; Müller et al., 2021). The low level of technological transformation outcomes may also be related to the concentration of papers on the factors, especially barriers (which inhibit SMEs from achieving higher levels of technology assimilation and BMI), with some studies dedicated to those barriers (e.g., Jhang & Chang, 2017; Birkel et al., 2019; Fanelli, 2021; Indrawati et al., 2020; Kumar, 2022). There is a concentration of papers in the first phases of technology assimilation, such as adoption (e.g., Bracci et al., 2022; Mujahed, 2022; Kumar, 2022).

The low level of adoption or assimilation leads to a low level of BMI. Finally, a few papers assess the performance outcomes expected from the technological transformation in SMEs. Next section presents a discussion of the findings.

2.4. Discussion

Based on our findings, we suggest some possible explanations for the fragmentation of the literature on technological transformation in SMEs. Firstly, this field is young, as shown in descriptive analysis (most studies were published between 2017 and 2022). Secondly, the context-dependence of technological transformation (in terms of technology, industry, age, and firm size) hampers its general conceptualization, with a concentration of papers in some technological contexts. Thirdly, the research streams are also fragmented individually as technology assimilation and BMI can be discussed in terms of process or outcome, resulting in a complex combination of the fields due to the high level of abstraction.

To improve the understanding of technological transformation in SMEs, we conduct an initial merge of technology assimilation and BMI fields in the context of introducing a technology by (i) classifying the papers' foci; (ii) identifying, unifying, and positioning the factors; (iii) identifying what is stated about the process, control variables and outcomes; and (iv) providing a conceptual framework.

We identified six main papers' foci, the most prominent being factors. The concentration of papers in analyzing factors was expected since existing literature reviews on technology assimilation and BMI in SMEs also focus on factors (Ahmad & Siraj, 2018; Hidayat et al., 2020). Moreover, as SMEs lag behind larger companies in adopting technologies, it is not surprising that papers focus on drivers to engage in technological transformation and the barriers that inhibit SMEs in this process. Moreover, from the classification of the factors, we demonstrate that although there are specific factors for technology assimilation and BMI, there are many common factors (especially enablers). The overlapping factors signal the holistic nature of technological transformation (e.g., partnership problems represent a barrier to technology assimilation and BMI).

The analysis of the factors depicts two crucial agents for technological transformation: the owner/manager and technology providers. Owner/managers are central to decision-making and creating conditions for technological transformation, which depends on their background and experience. Technology providers can support creating the conditions for using new technologies and also support SMEs in the strategic alignment of their BMs. The fact that providers need to change their BMs (not only concentrating on selling and installing

technology) to meet SMEs' needs is in line with the integrative technological transformation perspective on introducing technology.

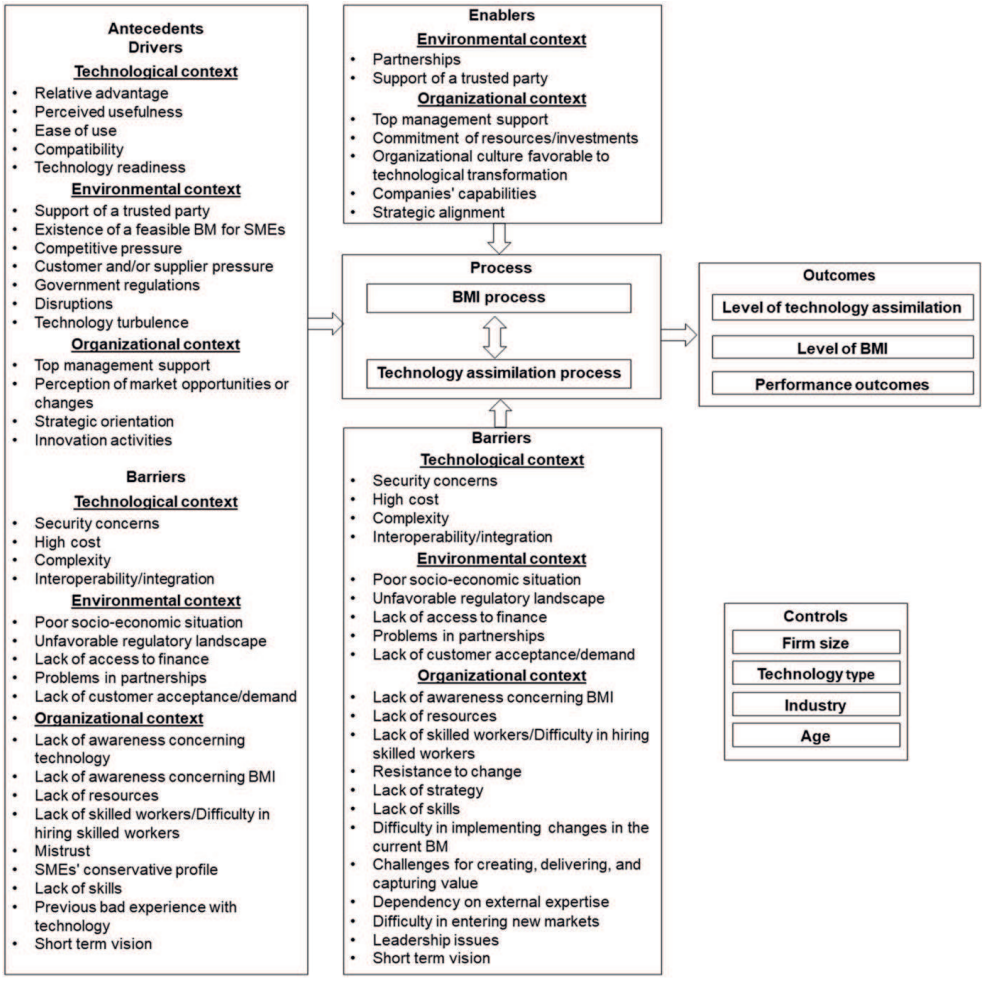
Regarding the process of technological transformation, the analysis highlights the need for external support, especially in cases where technology is complex or new and the SME does not possess specific capabilities (e.g., technical, financial, marketing). Moreover, there is a lack of conceptualization of the technological transformation process that may be linked to its context dependence. This lack of conceptualization challenges SMEs since technological transformation combines two already challenging processes with interrelationships.

The interrelationships between BMI and technology assimilation are not generally addressed in the literature, although the overlapping of the processes is suggested. From the analysis of the papers, we identified three relationships: (i) technology assimilation that drives BMI, (ii) BMI that mediates the relationships between technology assimilation and a company's performance, and (iii) BMI as a precursor of technology assimilation. The last relationship is not usually addressed in the literature but emerged from the analysis since technology acquisition can be problematic for SMEs.

The studies generally show a low level of transformation in terms of technology assimilation and/or BMI, and few studies evaluate the performance outcomes of technological transformation. This fact may be linked to the recentness of the papers and to SMEs' characteristics that lag in the technology adoption or experiment with a gradual transformation process compared to larger firms, which may result in the lack of studies on performance outcomes or the low level of outcomes reported. Finally, based on the content analysis, we derive the technological transformation framework (Figure 2).

To build this framework, we considered the overview of technological transformation: from its initiation to its outcomes. The drivers identified (presented in detail in section 2.3.2.2) are positioned at the beginning of the process, as they are the triggers for introducing new technology and/or changing the business with the new technology. The barriers (identified in section 2.3.2.3) are positioned according to the phase of technological transformation. Part of the barriers are positioned as antecedents (before technology introduction), and some barriers are positioned in the process of technological transformation (after introducing the technology). Enablers (presented in section 2.3.2.4) are positioned in the process of technological transformation as they are considered its facilitators. The overall transformation is influenced by control conditions (presented in section 2.3.2.5). Finally, the technological transformation process may result in three outcomes (as discussed in section 2.3.2.8): level of technology assimilation, level of BMI, and performance outcomes.

Figure 2: Technological transformation framework



2.5. Future research directions

Despite the significant number of papers identified on technological transformation in SMEs, the literature is still in development. We identify five research avenues that require further investigation, which are detailed as follows:

2.5.1. Research avenue 1: Process of technological transformation

Scholars highlight the importance of concept/construct clarity and the mechanisms that link different constructs (Foss & Saebi, 2017). In this regard, although previous studies suggest the overlap between technology assimilation and BMI processes, this interaction is not often

addressed (Sabatini et al., 2022). While we provide a framework for technological transformation, it can be extended by improving the understanding of the process of technological transformation.

Firstly, future studies can contribute by providing insights into the integration of technology assimilation and BMI processes. To build a more integrative framework, future studies can rely on the connection between technology-related theories and BMI theories, which is still underexplored. Another possibility is to combine these theories with other complementary theories (e.g., resource-based view, dynamic capabilities, etc.).

Secondly, the phases of the technological transformation process remain abstract. The literature is not homogeneous in presenting phases for BMI (Wirtz & Daiser, 2018), nor for the phases for technology assimilation (e.g., Fichman & Keremer, 1997; Zhu et al., 2006), let alone technological transformation phases. From a practical perspective, SMEs will need to receive insights to improve their understanding of technological transformation as well as information regarding tools and best practices to make the transformation process smoother. Future studies can provide theoretical contributions by describing phases, tools and methods for the technological transformation process (including technology assimilation and BMI) in the context of SMEs. Finally, it is unclear how managers/owners deal with both processes simultaneously when introducing technology, and empirical studies (especially longitudinal studies) can provide more detailed information.

2.5.2. Research avenue 2: Technological transformation in different settings and from different perspectives

There is a concentration of papers on specific technologies, mainly digital and 4.0 technologies, which have received increased attention due to new technological trends and the COVID-19 crisis. However, as the technology type conditions technological transformation, the studies' findings may not be extended to other technological contexts. Future research can dedicate efforts to different technological contexts and provide insight into (i) technological transformation paths for SMEs or (ii) BM patterns or configurations. For example, agri-food SMEs face pressure to comply with new trends in the food industry (e.g., waste management, extended shelf life, healthier food), which can be addressed by introducing food processing technologies (Rodgers, 2016). In this regard, studies could provide paths (including a sequence of phases and strategies to overcome expected barriers of technological transformation within an organizational context) or BM configurations for these SMEs. The food processing

technology is one example of a technological trend within a specific sector, but there are also other technological trends that future studies can address.

The technology transformation studies were mainly conducted in developed countries, which are considered years ahead of their counterparts in terms of technological transformation (Akpan et al., 2022). Thus, further research can analyze how technological transformation occurs in developing countries, providing insights into the specificities of this context. Finally, the studies identified mainly take the perspective of owner-managers of SMEs; future studies can consider the perspective of employees, which generally are the technology users. Taking the employees' perspective can provide insight into how users can better adapt to technological transformation.

2.5.3. Research avenue 3: Outcomes of technological transformation

Like Foss and Saebi (2017) reported in their literature analysis, part of the motivation to conduct most of the identified studies is the potential benefits of technological transformation, such as reducing cost, optimizing processes, accessing markets, introducing new products, and ultimately improving financial performance. However, most of the benefits expected from technologies are mainly reported at the theoretical level by the studies; few studies report performance gains with technological transformation or evaluate the performance consequences of technological transformation. In this regard, qualitative and quantitative research can be conducted to evaluate technological transformation's performance outcomes. Studies can also define performance measures for different technologies according to their objectives and phase of transformation. Finally, as studies generally report low transformation levels (in terms of the level of technological assimilation and level of BMI), further research can analyze in which conditions SMEs achieve higher transformation levels.

2.5.4. Research avenue 4: Risks and their mitigation in technological transformation in SMEs

Although the literature states that managing technological transformation in SMEs is challenging (Petzolt et al., 2022) and entails risks of failure (Nguyen et al., 2015), studies do not provide insights regarding SMEs that have experienced severe problems with technological transformation. Future studies can investigate cases where there is a discontinuation of technology use or severe consequences due to technological transformation, which can provide insights into the causes of failure and how to manage the risks of technological transformation.

Moreover, future studies can also address the role and development of risk management tools for technological transformation in SMEs.

2.5.5. Research avenue 5: BMI as a precursor of technology assimilation

Generally, the relationship discussed in the literature is technology assimilation that drives BMI (Sabatini et al., 2022), and little is known about how BMI can enable technology assimilation/adoption. In this regard, as BM may be seen as a supporting mechanism for technology adoption and scaling (Groot et al., 2019), future studies can evaluate how BMI can support SMEs in technological transformation. Future studies can assess how to build collaborative BMs or how technology providers may improve their value propositions to meet SMEs' needs, especially in the case of new and advanced technologies that are less accessible to SMEs (Akpan et al., 2022).

2.6. Conclusion

SMEs face pressure to introduce new technologies due to different requirements and changes in the business setting. Studies recognize the importance of technology assimilation, BMI, and their interplay in achieving the outcomes expected from new technology. However, the current body of knowledge on technological transformation is fragmented, and previous studies do not explicitly cover these concepts. The dispersed body of knowledge provides a vague understanding of the technological transformation phenomenon in SMEs. This work addresses this gap by performing a comprehensive SLR based on 165 peer-reviewed articles in which technology assimilation and BMI are presented within the context of introducing technology in SMEs. This SLR synthesizes the current state-of-the-art research on technological transformation in SMEs and contributes by (i) presenting the evolution of the field, the primary study approaches, and technological trends; (ii) classifying the paper's foci within the field; (iii) integrating and positioning technological transformation factors; (iv) inferring the interrelatedness between technology assimilation and BMI; and (v) providing a framework of technological transformation.

The findings indicate that technological transformation is a relatively new topic in the literature, and its combination remains abstract. The research domain is also concentrated in various technological contexts (e.g. digital technologies, e-commerce, and industry 4.0). In this sense, we develop a general framework for the subject, as the antecedents, processes, and outcomes were extracted from studies in various contexts.

The findings demonstrate that most of the papers focus on factors. These factors were identified, integrated, and positioned in the technological transformation framework. The analysis of factors and processes of technological transformation suggests an overlap between technology assimilation and BMI, and we provide insight regarding their relationships (three relationships were identified). Results also show a limited number of studies assessing the outcomes of technological transformation in SMEs, and that, generally, SMEs present a low transformation level. Finally, the limitations in the keywords used to perform the paper's search impact this work. We used generic terms without considering keywords for specific technologies (e.g., industry 4.0, digitalization) since the scope of this paper is general. Secondly, we only selected papers that present the term "business model" since we were interested in papers that explicitly address the BMI concept. Thirdly, papers focusing on the individual streams (technology assimilation or BMI) were not selected since they are out of the scope. The authors' subjectivity also limits the papers' analysis and classification because only the authors' viewpoints were contemplated.

3

Exploring technological transformation: empirical insights into SMEs' responses to new technologies in the EU agri-food sector

Chapter 3: Exploring technological transformation: empirical insights into SMEs' responses to new technologies in the EU agri-food sector

Abstract

Technological innovation is becoming a central strategy for small and medium-sized enterprises (SMEs) seeking to respond to the increasingly demanding and challenging business environment. Research indicates that to fully leverage technological innovation, SMEs must undergo a technological transformation that involves both technology assimilation and business model innovation (BMI). However, existing research typically treats these processes separately and, in the SME context, concentrates largely on adoption decisions, leaving the overall transformation process and its outcomes only partially understood. To address this gap, this article draws on a multiple-case study of 39 EU agri-food SMEs to examine how the technological transformation process unfolded and the outcomes it generated. Using retrospective and abductive analyses, we classify SMEs by levels of technology assimilation and BMI, and perceived performance, and identify environmental, technological, and organizational conditions that shape distinct transformation trajectories. This study identifies a dominant efficiency-oriented pathway among incumbent agri-food SMEs deploying mainstream technologies for mainstream products, alongside more complex BMI trajectories concentrated among young firms combining innovative technologies or novel business ideas. The levels of technology assimilation were shaped primarily by barriers, whereas BMI levels were structured mainly by drivers, technology scope, and business-idea disruptiveness. Across cases, technology assimilation and BMI overlapped particularly in decision-making and value creation, with operational reconfiguration typically preceding value proposition and capture. Performance depended not on either process in isolation but on their coordination through strategic decision-making, technical and business deployment, partner orchestration, and market-building. Many SMEs, therefore, remained in an intermediate state in which technology assimilation advanced faster than commercialization, while value-capture bottlenecks varied across BMI levels. Finally, avenues for future study are suggested.

Keywords: Technological transformation; Business model innovation; Technology assimilation; Agri-food SMEs; Technological innovation, Multiple case study

This paper is authored by Giustina Pellegrini, Camila Silva de Mattos, Geoffrey Hagelaar, and Wilfred Dolfsma.

3.1. Introduction

Small and medium-sized enterprises (SMEs) play a crucial role in global economic and societal development, representing the majority of businesses and employing over half of the global workforce (Cantele et al., 2020). SMEs face mounting pressure to embrace technological innovations to remain competitive, ensure survival, and respond to rapidly changing business environments (Donbesuur et al., 2020; Paoloni et al., 2022).

Against this backdrop, research on technological innovation in SMEs has expanded considerably, largely motivated by its potential benefits (Indrawati et al., 2020; Chege & Wang, 2020). Despite this growing attention, limited understanding remains of the broader organizational processes through which SMEs introduce and exploit new technologies to realize these benefits (Pellegrini et al., 2023; de Mattos et al., 2024).

Recent research suggests that technological innovation triggers an organizational transformation process in which two interdependent dynamics are central: technology assimilation[7] and business model innovation (BMI) (Baden-Fuller & Haefliger, 2013; Smajlović et al., 2019; Sabatini et al., 2022). Technology assimilation involves integrating new technologies into an organization's systems and practices, spanning from initial awareness to full implementation, ensuring their effective use (Zhu et al., 2006; Baird et al., 2017). Concurrently, BMI reshapes the company's business model (BM) to unlock the value of technological innovations, creating pathways for monetization, enhancing revenue generation, and operational efficiency (Chesbrough, 2007; Foss & Saebi, 2017). Prior work indicates that these processes overlap during decision-making, organizational change, and outcome realization, and that weak coordination between them often undermines performance (Smajlović et al., 2019; Sabatini et al., 2022).

Despite increasing recognition of these interdependencies, technology assimilation and BMI have largely developed within separate research streams (de Mattos et al., 2024). This fragmentation reflects both analytical challenges in integrating distinct theoretical traditions and the historical evolution of academic debates. In practice, however, technological and business changes typically unfold within the same transformation effort, motivating scholars to treat this dynamic as a more integrated object of analysis.

[7] Technology assimilation is adopted as an overarching label to ensure consistency. The literature most frequently refers to closely related phenomena through the terms of adoption, implementation, and technological innovation, each of which tends to foreground a particular segment of a broader process. Adoption commonly denotes the decision-making, implementation its embedding within organizational processes, and technological innovation the novelty associated with the technology itself. Although these terms are sometimes employed in a more comprehensive manner, we adopt technology assimilation to capture the full organizational trajectory through which technologies move from early awareness, introduction, and full deployment within the firm.

This shift is particularly visible in more recent research on digital transformation, where the pace and scope of change make it difficult to disentangle technological from business processes (Warner & Wäger, 2019; Sousa-Zomer et al., 2020). Studies on SMEs increasingly adopt similarly integrative perspectives, referring to these dynamics as technological transformation (Pellegrini et al., 2023; de Mattos et al., 2024). Building on this literature, we use technological transformation to denote the overarching organizational process through which firms integrate and exploit new technologies, encompassing both technology assimilation and BMI.

Within SME literature on technological transformation, two recurring limitations remain. First, technology assimilation and BMI are still often treated as loosely connected analytical objects despite their acknowledged interdependence (de Mattos et al., 2024). Second, research continues to emphasize initial adoption decisions and their factors (Bracci et al., 2022; Mujahed, 2022; Kumar et al., 2022). Although this focus on early stages is understandable, particularly in explaining SMEs' adoption behavior and their lag relative to larger firms, technological transformation rarely ends with adoption and cannot be reduced to either technological or business change alone. This combination of fragmented insights limits understanding of how SMEs manage transformation processes and how innovation efforts are translated into realized outcomes.

These gaps are especially consequential for SMEs, which pursue technological transformation under severe constraints of financial resources, time, and managerial capacity (O'Toole, 2003; Priyono et al., 2020). Uncertainty regarding future benefits and limited guidance on managing transformation further amplify these challenges (Bouwman et al., 2019; Müller et al., 2021). The agri-food sector is a particularly suitable empirical context to study technological transformation because it is dominated by SMEs facing strong pressures to invest in new technologies to meet food safety regulations, sustainability demands, and intensifying competition (Minarelli et al., 2015; Tell et al., 2016; Ancín et al., 2022). Accordingly, this study addresses two research questions:

RQ1: How do EU agri-food SMEs assimilate new technologies, innovate their business models, and perceive performance outcomes from the technological transformation process?

RQ2: What conditions influence the transformation levels and performance perceptions among EU agri-food SMEs?

To address these questions, we conduct a multiple-case study of 39 EU agri-food SMEs. Using retrospective analysis, we classify firms by levels of technology assimilation, BMI, and perceived performance and compare configurations of outcomes across cases. This design

enables the identification of recurrent transformation patterns and the contextual conditions that shape them. Building on this comparative analysis, the study advances a process-oriented and configurational perspective on technological transformation by explaining how specific combinations of conditions produce heterogeneous SME trajectories (Sabatini et al., 2022; Pellegrini et al., 2023).

The contribution is particularly relevant for agri-food innovation research, where existing typologies often focus either on technological innovation or BMI in isolation (Minarelli et al., 2015; Barth et al., 2017; Ulvenblad et al., 2018; Long et al., 2018; Nosratabadi et al., 2020). By integrating these perspectives, this study conceptualizes technological transformation as a configuration-based organizational process and provides a comparative basis for analyzing heterogeneous SME pathways.

The chapter is presented as follows: section 3.2 presents the theoretical background, section 3.3 describes the research method, and section 3.4 shows the findings. The final sections, discussion (3.5) and conclusions (3.6) conclude the chapter and offer recommendations for future research.

3.2. Theoretical background

3.2.1. Technological transformation in the general context of SMEs

Technology assimilation and BMI are terms frequently used to describe both organizational change processes and the transformation states firms ultimately reach (Foss & Saebi, 2017; Ahmad & Siraj, 2018; de Mattos et al., 2024). In process terms, technology assimilation refers to the trajectory through which firms move from initial awareness to full integration of a technology into organizational routines (Ahmad & Siraj, 2018), whereas BMI denotes the sequence of organizational adjustments through which firms reconfigure activities, structures, and value mechanisms (Abdelkafi et al., 2013).

In terms of outcomes, these concepts capture the extent to which such processes have been realized. Technology assimilation outcomes reflect the degree to which technologies are embedded in operations, while BMI outcomes indicate the magnitude of change achieved in BM elements. Higher assimilation levels, therefore, correspond to more pervasive technological deployment, whereas higher BMI levels signal more far-reaching reconfigurations of the firm's BM (Sabatini et al., 2022).

Across both processes and outcomes, prior research increasingly portrays technology assimilation and BMI as intertwined components of technological transformation (Pateli & Giaglis, 2005; Chesbrough, 2007; Tongur & Engwall, 2014; Holzmann et al., 2019; Pellegrini

et al., 2023). Rather than unfolding independently, they tend to co-evolve through firms' decision-making, implementation trajectories, and eventual transformation levels (Smajlović et al., 2019; Sabatini et al., 2022; de Mattos et al., 2024).

At the outset of technological transformation, decisions may be triggered by perceived technological advantages (Akpan et al., 2021) as well as by market opportunities enabled by their use (Bouwman et al., 2019). SMEs often consider both aspects simultaneously, assessing technological benefits alongside potential business opportunities. For instance, external pressures from customers or supply-chain partners may further influence such decisions, either by encouraging firms to meet technological requirements or by stimulating the pursuit of new business opportunities enabled by these technologies (Gatautis & Vitkauskaite, 2009).

Interdependencies persist during implementation, as the organizational changes required to operationalize new technologies extend into domains commonly associated with BMI. Activities are reorganized, value propositions reconsidered, and revenue logics adjusted. In practice, technology assimilation and BMI therefore unfold as part of the same organizational response to technological innovation. For instance, SMEs introducing advanced technologies typically reorganize production processes, redesign workflows, and develop new technical and analytical skills, while simultaneously exploring new service offerings and revenue mechanisms, as documented in digital manufacturing contexts (Müller et al., 2018).

These linkages extend to outcomes. Prior studies suggest that the degree to which technologies are embedded in operations often covaries with the extent of BMI, particularly when firms deploy similar technologies toward comparable strategic aims (Westerlund, 2020).

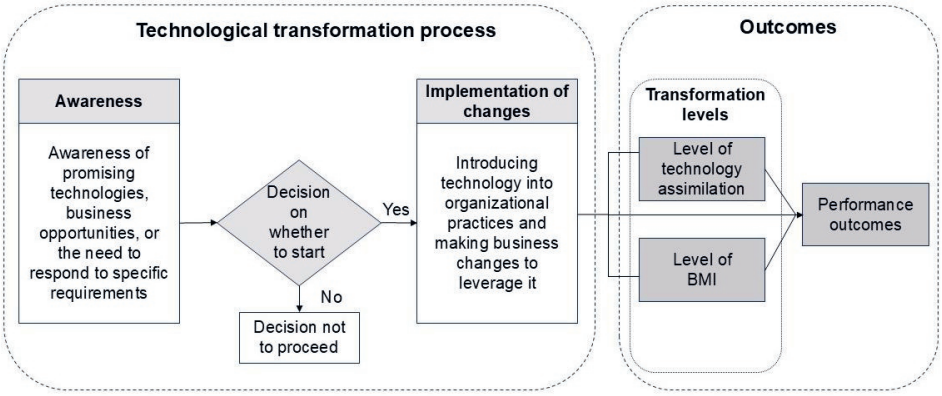
Despite accumulating evidence of these interconnections, explicit integration of technology assimilation and BMI remains relatively recent (Sabatini et al., 2022; de Mattos et al., 2024). This reflects the distinct theoretical traditions underlying each stream. Although digital transformation research increasingly adopts integrative frameworks, these remain centred on digital technologies (Kane et al., 2015; Singh et al., 2020; Sousa-Zomer et al., 2020; Vaska et al., 2020), leaving other technological contexts less explored.

Moreover, SME-focused digital transformation research is still emerging (Vrontis et al., 2022; Ragazou et al., 2022; Petzolt et al., 2022), while the broader technological transformation literature continues to emphasize adoption decisions over the overall process (Indrawati et al., 2020; Fanelli, 2021; Bracci et al., 2022).

This study advances an integrative framework (Figure 3) to address these gaps. The framework synthesizes these dispersed insights by explicitly linking technology assimilation, BMI, and

performance within a unified view of technological transformation for comparative analysis across heterogeneous technological and strategic contexts.

Figure 3: Technological transformation – From process to outcomes
Developed by the authors



In the technology assimilation literature, levels are commonly operationalized through the degree to which technologies are embedded in organizational activities (Purvis et al., 2001; Brown & Lockett, 2004; Ahmad & Siraj, 2018). More recent work, largely focused on digital technologies, refines these assessments by examining the breadth of application across organizational functions such as management, marketing, sales, and production (Ibarra et al., 2020; Moeuf et al., 2018; Sabatini et al., 2022). While analytically powerful in digital contexts, such function-based classifications are less readily transferable to settings where innovations are concentrated in specific production stages, as is often the case in food processing or process technologies.

To enable cross-technology comparison, this study adopts the staged assimilation framework proposed by Fichman and Kemerer (1997), which conceptualizes technology assimilation as a multi-phase organizational trajectory encompassing awareness, interest, evaluation or trial, commitment, limited deployment, general deployment, rejection, and discontinuance (see section 3.3). This approach captures variation in organizational engagement over time in terms of scope of use, persistence, and strategic commitment, making it particularly suitable for analyzing SMEs facing resource constraints and shifting priorities.

BMI is commonly conceptualized along three core value elements: value proposition, value creation, and value capture, which together specify what is offered, how offerings are produced

and delivered, and how economic value is appropriated (Bocken et al., 2015; Müller et al., 2018; Schneckenberg et al., 2017; Reim et al., 2022).

The scope of BMI varies with the breadth of these changes. Adjustments confined to a single element reflect relatively incremental innovation, whereas more complex forms involve coordinated reconfigurations across multiple elements (Taran et al., 2015; Yeger & Shenhar, 2019; Sabatini et al., 2022). This breadth is, in turn, shaped by the extent of technology assimilation and by technological characteristics (Bouwman et al., 2018; Leelasantitham, 2020).

Technological transformation is ultimately reflected in performance outcomes that depend on how effectively technology assimilation and BMI align. Prior research links such transformation to cost reductions, process optimization, market expansion, product innovation, and financial performance, although the magnitude and direction of these effects vary with technological attributes and strategic intent (Apostolov & Coco, 2021; Fanelli, 2021).

3.2.2. Technological transformation in agri-food SMEs

Technological transformation has become a central strategic issue for agri-food SMEs, which face simultaneous pressures related to regulatory compliance, traceability, perishability, sustainability demands, and shifting market expectations (Wang et al., 2023; Joshi et al., 2023; ElBeheiry & Balog, 2023).

Despite its growing relevance, research offers limited systematic insight into how technological transformation unfolds in this sector (Pellegrini et al., 2023). Prior studies have largely examined either technology assimilation or BMI in isolation (Ibrahim et al., 2017; Jain et al., 2021; Dagevos & Lauwere, 2021), resulting in a fragmented understanding that obscures transformation as an integrated organizational process. This study addresses this gap by identifying recurring patterns of technological transformation in agri-food SMEs and examining how technology assimilation and BMI co-evolve within this sector.

3.3. Research Method

3.3.1. Research design

As technological transformation remains an emergent and theoretically fragmented field (de Mattos et al., 2024; Pellegrini et al., 2023), this study adopts an exploratory, abductive research design. Exploratory research is particularly appropriate for examining contemporary organizational phenomena in contexts where existing theory remains fragmented or underdeveloped and where empirical inquiry is required to identify patterns, refine concepts,

and generate new analytical insights (Stebbins, 2001). Accordingly, the study iterated between prior literature and case evidence, using abductive reasoning to interpret cross-case regularities and to explain why SMEs reached different levels of technology assimilation, BMI, and performance.

The study adopts a multiple-case study design to support analytic generalization through cross-case comparison (Yin, 2011). This design enables the identification of recurrent patterns across cases and the examination of how different configurations of organizational, technological, and environmental conditions are associated with the transformation trajectories of agri-food SMEs.

3.3.2. Data collection and analysis

To identify suitable cases, we constructed a database of approximately 2,000 agri-food firms through internet searches and contacts from prior EU-funded projects. Firms were included if they met the European Commission definition of SMEs[8] and operated in the agri-food sector. The sampling strategy aimed to maximize heterogeneity in firm size and geographic location to capture variation in technological transformation trajectories. In line with sector statistics (FoodDrinkEurope, 2020), microenterprises constituted the largest share of the contacted population.

Case selection followed a purposive sampling logic based on three criteria: recent introduction of new technologies within the preceding three years, SME status in the EU agri-food sector, and willingness to provide detailed information on transformation trajectories. All eligible firms were contacted by email with a standardized description of the study. Of the 56 firms expressing interest, 17 were excluded due to unmet criteria, insufficient information, or incomplete interview material. The final sample comprised 39 SMEs: 28 micro, 8 small, and 3 medium-sized firms across 10 EU countries (see Appendix A).

Primary data were collected through semi-structured interviews with founders, CEOs, and innovation managers, enabling retrospective reconstruction of technological transformation processes. Interview protocols covered organizational context, introduced technologies, drivers, barriers, and enablers, implementation strategies, changes in business activities, perceived performance outcomes, and future innovation plans.

Interviews were conducted by telephone or videoconference in 2019, audio-recorded, transcribed verbatim, and systematically coded. Construct validity was enhanced through

[8] The European Commission (2003) classifies SMEs into three categories based on both the number of employees and turnover. Micro enterprises have 0 to 9 employees and a turnover of up to €2 million, small enterprises have 10 to 49 employees and a turnover of up to €10 million, and medium-sized enterprises have 50 to 249 employees with a turnover of up to €50 million.

triangulation with secondary sources, including company websites, public reports, and project documentation.

Consistent with the abductive research logic, data analysis combined theoretically informed coding with inductive pattern detection. Initial categories were derived deductively from the conceptual framework (Table 8) and captured levels of technology assimilation and BMI, performance, and contextual conditions.

Table 8: Categories of analysis

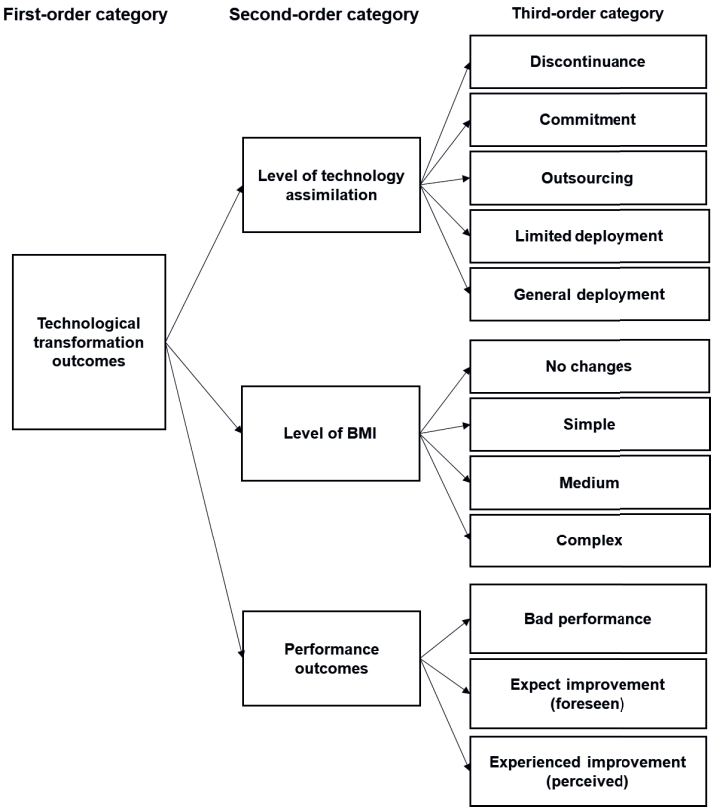
Category	Description	References
Technological transformation outcomes	**(i) level of BMI:** Similar to Sabatini et al. (2022), we classify the level of BMI according to the number of changes in elements (in our case, value elements). We classify them as *simple* (when one value element is changed), *medium* (when two value elements are changed), or *complex* (when three value elements are changed). **(ii) level of technology assimilation:** We draw on the staged assimilation framework of Fichman and Kemerer (1997). In addition, we incorporated an outsourcing phase to capture a frequent configuration among SMEs. *Awareness:* Decision makers are aware of new technologies; *Interest:* The organization is learning about or planning to use the technology; *Evaluation/Trial:* The organization has acquired and is trialing the technology; *Commitment:* The organization is committed to using the technology in a specific part of production; *Limited Deployment:* Technology use is initiated but still limited; *General Deployment:* The technology is fully implemented across the organization; *Rejection:* The technology is evaluated but rejected for current use; *Discontinuance:* The technology was once used but is no longer in use. *Outsourcing:* core technological activities are performed by external partners rather than being integrated internally. (iii) **performance outcomes:** how the companies perceived the performance after technological transformation.	Fichman and Kemerer (1997); Foss and Saebi (2017); Sabatini et al. (2022); de Mattos et al. (2024)
Conditions for technological transformation	We evaluate drivers, barriers, and enablers that, in combination with the controls and context, shape the conditions of technological transformation.	Gatautis et al. (2019); Groot et al. (2019); Pellegrini et al. (2023); de Mattos et al. (2024)

The analytical structure followed a hierarchical coding logic formalized in a coding tree (Figure 4). First-order categories captured firm-level technological transformation outcomes, while second-order categories distinguished three core dimensions: level of technology assimilation, level of BMI, and perceived performance outcomes. Third-order categories provided finer-grained distinctions, enabling the classification of SMEs into specific outcome configurations. To account for heterogeneity, temporal variation in transformation onset was incorporated into trajectory reconstruction. The sample included both newly founded and incumbent SMEs, which required differentiated treatment when assessing BMI. For incumbents, BMI was

evaluated relative to pre-existing BMs, whereas for younger firms developing their BMs alongside technology assimilation, BMI was assessed against prevailing sectoral practices in this traditionally low-technology context (Minarelli et al., 2015). Variation in introduced technologies and strategic purposes was also incorporated to reflect differences in technological scope and application domains.

All 39 cases were independently coded by two authors and discussed in iterative rounds to reach analytical consensus, enhancing reliability and ensuring consistent application of the classification scheme. The following section presents the resulting empirical findings.

Figure 4: Coding tree – technological transformation outcomes



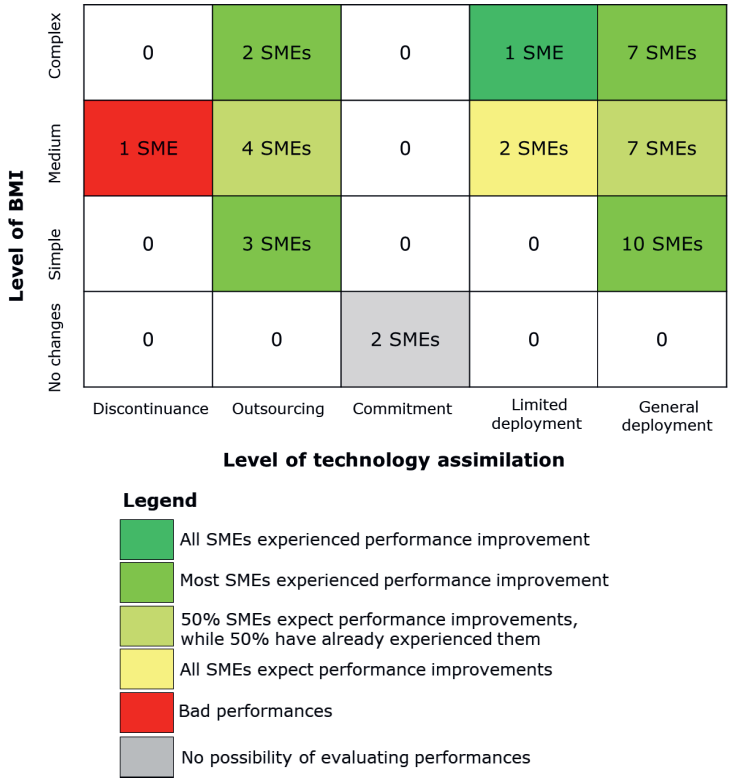
3.4. Results

3.4.1. Understanding the outcomes of technological transformation

We classified the 39 agri-food SMEs into outcome configurations summarized in Figure 5. The figure positions firms along two analytical categories: level of technology assimilation on the

horizontal axis and level of BMI on the vertical axis, with perceived performance represented as a third analytical category via color coding. This visualization reveals 10 empirically grounded SME groups that represent recurring transformation profiles.

Figure 5: Technological transformation outcomes: classification of the companies



Cross-classification – description of SME groups

1. Simple level of BMI and general deployment of technology (10 SMEs)

This group represents the largest cluster in the sample and consists primarily of incumbent SMEs operating in mainstream food segments such as juices, olive oil, and fresh produce. These firms mainly assimilated conventional processing and farming technologies, including flow pasteurization systems, tractors, and controlled storage chambers, to improve operational efficiency through energy savings, waste reduction, increased throughput, and enhanced storage conditions.

Across cases, technology assimilation was typically concentrated within a single business function, most often farming or processing. Accordingly, BMI remained confined to changes

in value creation. One exception concerns a younger retail-oriented SME that introduced an online platform to promote its products, thereby shifting toward changes in value capture.

Performance outcomes were predominantly positive. Eight SMEs reported improvements, most often productivity gains. Companies 14 and 16, for example, described substantial increases in juice output following the installation of flow pasteurization systems, while another firm reported a 50 percent reduction in post-harvest losses after adopting controlled storage facilities. Two SMEs were still assessing the effects on performance at the time of the interviews. In one case, the interviewee lacked direct access to performance data. In another, the SME achieved its technological objectives in livestock farming but reported that sales had not increased, and it was therefore seeking new commercial partnerships to improve commercialization outcomes.

2. Simple level of BMI and outsourcing technology (3 SMEs)

Similar to Group 1, SMEs in this cluster are incumbent and operate in mainstream food segments such as olive oil and fresh fruit. They relied on established food processing technologies to improve efficiency, particularly by increasing output and reducing spoilage linked to short shelf-life. Unlike Group 1, however, these firms outsourced technological functions due to the high investment costs involved. As a result, technology assimilation remained externalized, and BMI was largely confined to adjustments in value creation.

Performance outcomes were mixed. Two firms reported improvements, while one experienced poor performance. Company 2, for instance, outsourced cold storage facilities to extend product shelf-life and support its export strategy. Leveraging prior international experience and network ties, the firm translated these operational gains into higher foreign sales. Company 23 similarly increased olive oil processing capacity through outsourced milling and perceived positive performance effects. By contrast, Company 18 reported weaker performance at the time of the interviews: it outsourced milling to scale olive oil production, and unstable yields constrained output, preventing full use of the expanded processing capacity. The technology also supported a premium positioning by preserving organoleptic qualities through low-temperature processing, but certification requirements delayed access to higher-value markets. As a result, the firm failed to achieve either its scaling objectives or its premium pricing strategy, thereby weakening overall performance despite operational improvements.

3. Medium level of BMI and general deployment of technology (7 SMEs)

SMEs in this group are predominantly incumbents that introduced technologies that, while not cutting-edge, are not yet widely diffused within the sector, such as aquaponic systems and

production line reconfigurations. These technologies were deployed internally, leading firms to modify both farming and food processing routines. Unlike Groups 1 and 2, these adjustments extended beyond efficiency improvements and required changes in product characteristics, thereby affecting not only value creation but also value proposition. Examples include altering the flavor profiles and composition of dried tomato and dairy products, shifting production processes to enable the production of fresh fish and vegetables without preservatives, and reconfiguring fruit plantations to respond to changing market demand.

To implement these transformations, most SMEs mobilized external expertise. Three collaborated with specialized technology providers, while another three relied on cooperatives that supported both equipment acquisition and workforce training. This interorganizational support enabled the general deployment of the technologies, yet it did not guarantee successful commercialization.

Performance outcomes within the group were heterogeneous. Three encountered difficulties in marketing their upgraded products. Company 39, for instance, enhanced olive oil quality through advanced milling techniques but struggled to compete in a saturated domestic market. One firm was still assessing performance effects at the time of the interviews. By contrast, the remaining three SMEs reported improvements in productivity and product quality, along with stronger alignment with niche-market demand, enabling them to command higher prices and achieve positive performance outcomes.

4. Medium level of BMI and outsourcing technology (4 SMEs)

This group consists exclusively of young microenterprises that developed novel beverage- and ingredient-based products with clearly differentiated value propositions. In contrast to incremental adaptation strategies, these SMEs pursued a medium level of BMI by simultaneously innovating value propositions and value creation processes. Rather than modifying existing offerings, they launched new products such as milk-based olive oil shots positioned around health benefits and honey-based alcoholic beverages framed around sustainability-oriented consumption.

Because standardized production routines were largely absent for these product categories, technological development and BM formation unfolded in parallel. Several SMEs relied on outsourcing arrangements to compensate for limited internal resources. For instance, Company 10 collaborated closely with an external producer to manufacture an olive oil dairy shot, yet ongoing experimentation was required to stabilize quality, shelf-life, and production consistency.

At the time of data collection, most firms had not yet realized full performance effects and anticipated future improvements as production volumes expanded. Persistent technical bottlenecks related to stability, packaging, and scaling, combined with difficulties in customer acquisition and reputation building, constrained short-term sales potential. One exception was Company 1, which benefited from ties to an established sister firm. It leveraged supplier networks, customer access, and market knowledge to outsource production of a new sports product variant, thereby accelerating commercialization and market penetration.

5. Medium level of BMI and limited deployment (2 SMEs)

This group comprises two microenterprises that achieved limited technological deployment because their core production processes for their novel products were still under development. Both SMEs were attempting to scale plant-based ingredients and fig molasses from laboratory or craft settings toward industrial production, leaving technology assimilation incomplete at the time of data collection. Despite this restricted deployment, the firms pursued a medium level of BMI by simultaneously redefining their value propositions and redesigning value creation activities around new processing methods. Performance outcomes remained uncertain. Neither firm had yet stabilized production at commercial scale, but both anticipated future performance improvements once technological functions matured and deployment broadened.

6. Medium level of BMI and discontinuance (1 SME)

This group consists of a single microenterprise that pursued a medium level of BMI but ultimately discontinued using the technology. The SME initially reconfigured both its value proposition and value creation by introducing cold-pressed juices produced via high-pressure processing (HPP). Given the capital-intensive nature of HPP, production was outsourced, while the company sought to reposition its offering around superior freshness and quality. Despite these technical advantages, market uptake remained limited. Consumers were unfamiliar with the processing technology and reluctant to pay the associated price premium, while retailers showed little willingness to support higher-priced products. As operating costs exceeded commercial returns, the SME abandoned the outsourced HPP process and reverted to its original real-time juice production model.

7. Complex level of BMI and general deployment of technology (7 SMEs)

This group comprises predominantly young and microenterprises that pursued technologically intensive transformations combined with extensive reconfigurations of their BMs. Most firms

introduced cutting-edge food processing or farming technologies, such as sensor-equipped machinery and microgreen production systems, while two others relied on digital platforms to restructure relationships between producers and consumers.

For firms deploying advanced food technologies, the limited availability of specialized providers and the novelty of the processes compelled them to internalize experimentation and learning. These SMEs therefore adopted incremental, trial-based implementation paths, progressively refining both technological routines and commercial applications. In several cases, this experimentation enabled firms to build distinctive capabilities and reposition themselves as technology providers or consultants, thereby extending BMI beyond production activities to encompass new value propositions, delivery mechanisms, and revenue streams. For example, two companies now commercialize advisory services related to microgreen systems and pruning waste management solutions.

Digital platform adopters experienced smoother technical assimilation but faced commercial frictions related to investment intensity and customer adoption. One firm achieved substantial cost reductions through sensor deployment, cutting production costs by nearly an order of magnitude and translating these efficiency gains into higher revenues. By contrast, the platform-based SMEs continued to struggle with user acquisition and behavioural inertia among consumers accustomed to supermarket purchasing formats. One case involved a platform that connected farmers directly with consumers to offer lower-priced, healthier food options, yet uptake remained constrained by convenience-driven purchasing habits.

Overall, performance outcomes in this group were largely positive. Five SMEs reported growth through market entry, sales expansion, or capability-based differentiation, while two firms anticipated future improvements as customer bases scale and commercial models stabilize.

8. Complex level of BMI and limited deployment (1 SME)

This cell comprises a single firm that pursued a highly transformative platform-based BM but remained at a limited deployment stage of technological assimilation. The company developed an e-commerce system organized around crowdfunding meat purchases, restructuring the supply chain by pre-selling mixed boxes containing all cuts of an animal before slaughter, reducing food waste. This model simultaneously altered the value proposition by appealing to sustainability-oriented consumers, the value-creation logic by coordinating production upstream, and the value-capture mechanism by shifting transaction timing.

Despite this extensive BMI, technological deployment remained partial as the platform continued to evolve and expand geographically. Performance outcomes were cautiously

positive. The firm reported steady growth in revenues, the number of participating producers, and customer relationships, but continued to face operational bottlenecks in logistics coordination, quality preservation, and digital infrastructure capacity. These constraints limited scaling and explain why the transformation had not yet progressed to full deployment.

9. Complex level of BMI and outsourcing (2 SMEs)

This group consists of two microenterprises that pursued complex BMI while relying heavily on external partners for technological functions. Both firms developed a circular production system that reconfigured supply chains, product offerings, and revenue structures. One company adopted a circular model that repurposes coffee waste to produce fungi-based products, thereby redefining its value proposition and reorganizing value creation through residue-collection networks. Value capture was oriented toward environmentally conscious retailers and customers, including the original waste suppliers. Initial performance gains were primarily reputational and relational, reflected in increased customer acquisition and brand visibility. The firm subsequently pursued financial consolidation through export initiatives and partnership expansion.

The second SME initially outsourced spirulina production while building internal knowledge through collaboration with universities and industrial partners. Over time, it transitioned from technology user to technology provider, marketing tailored production systems and consultancy services to business partners related to spirulina processing. This strategic shift extended BMI across all value elements and created a new revenue stream based on technological services. Performance improvements were associated with growing demand in an emerging market characterized by limited competition and strong partner embeddedness.

10. Commitment and no changes (2 SMEs)

This group captures SMEs that are committed to acquiring advanced technologies but remain unable to translate this commitment into operational deployment or BMI. Both SMEs invested in specialized systems for specific functions but encountered severe resource and capability constraints. One consultancy firm purchased a customer relationship management (CRM) system to enhance client analytics, but lacked sufficient staffing and time to complete technology assimilation. The second SME planned to install monitoring systems for irrigation, lighting, and ventilation to optimize crop production, but postponed the acquisition due to financial constraints. In both cases, incomplete assimilation prevented spillovers into BMI, and performance effects could not yet be assessed.

The above-identified groups are summarized in Table 9.

Table 9: Cross-classification result

Group	TA Level	BMI level	N	Description	Perceived performances
1	**General**	**Simple**	10	• Incumbent SMEs produce mainstream food and beverage products. • 9 have integrated conventional technologies to enhance their business processes, resulting in changes in value creation • 1 young SME adopted an online platform to acquire new customers, leading to a change in value capture	• 8 registered improved performance due to increased productivity (e.g., reducing losses by 50%) • 2 are still evaluating or foreseeing improvement (e.g., 1 improved farming practices for high-quality meat but saw no sales boost)
2	**Out**	**Simple**	3	• Incumbent SMEs that offer conventional food products with conventional technologies in the processing phase (to enhance efficiency), resulting in changes in value creation • Although the technologies are widely used in the industry, they outsource them due to the high cost	• 2 improved by increased sales • 1 registered bad performance due to inadequate production and low margins
3	**General**	**Medium**	7	• Incumbent SMEs that adopt technologies not widely disseminated but not cutting-edge to innovate their products (changes in value creation and proposition) and meet changing customer needs • Changes in farming and processing, with technical or financial support	• 4 anticipate performance improvement or are still evaluating • 3 have successfully achieved their technology assimilation goals, but are encountering difficulties in selling the products
4	**Out**	**Medium**	4	• Micro new enterprises specialize in crafting innovative beverages and raw ingredient-based products with unique value propositions • Instead of changing existing offerings, they create new products that require changes in existing mainstream procedures (e.g., health-promoting products) • Prioritizing expanding and consolidating their business, over-investing in technology (business and outsourcing simultaneously)	• 3 struggling to establish themselves in the market (improvements expected, although they face technical challenges related to stability, packaging, and scaling up production, which directly affects their sales) • 1 reported increased profits and successful technology assimilation due to the experience and knowledge gained from the previous business

Continuation of Table 9: Cross-classification result

5	**Limited**	**Medium**	2	• Limited deployment due to the new entrance of innovative products into the market. • Time required to scale the production from a craft or lab scale to an industrial scale	• Unmet technology assimilation goals affect their performance perception and lead to expectations of improvement.
6	**Discont**	**Medium**	1	• HPP technology to produce cold-pressed juices with high health value • Lack of market interest and the high cost of maintaining the technology	• Bad performance: Clients and retailers were hesitant to pay the higher price, and there was a lack of market interest (processing technology unfamiliar to customers)
7	**General**	**Complex**	7	• Young and micro companies • 5 using cutting-edge food processing and farming technologies, offering a unique product or novel application techniques to become leaders in their field, and transitioning into technology providers themselves • 2 using digital platforms to disrupt the existing logic of food supply chains, acting as intermediaries between producers and consumers, and encountering difficulties in capturing value	• 5 perceived good performances since they are serving the market with new products and, in some cases, are entering relatively new markets • 2 foresee improvement since they face challenges in acquiring users
8	**Limited**	**Complex**	1	• An e-commerce platform that crowdfunds meat purchases, changing the meat supply chain. • Ongoing improvements demonstrate its disruptive potential and its ability to adapt to new logistics.	• Perceived improvement based on steady growth, considering key metrics like revenues, box producers, and customer relationship metrics
9	**Out**	**Complex**	2	• Micro-enterprises are discovering innovative solutions that have the potential to revolutionize their sectors • 1 has transcended its role as a technology user to provider, emerging as a leader in their field	• 1 observed a positive trend in performance due to the acquisition of new customers and an enhancement of its reputation • 1 has foreseen performance improvement, planning to broaden its business presence into additional countries
10	**Comm**	**No changes**	2	• Committed to costly and cutting-edge technologies • Lack of expertise, knowledge, and financial resources; recent adoption • No changes in their BMI	• No possibility of evaluating performances

3.4.2. Understanding the conditions for the outcomes of technological transformation

The following subsections identify the drivers, barriers, and enablers observed across the cases. Section 3.4.3 then examines how different configurations of these factors combined to other contextual characteristics generate distinct technological transformation trajectories.

3.4.2.1. Drivers

We identified drivers shaping SMEs' initial decision-making, with distinct patterns across BMI levels. SMEs exhibiting simple BMI levels were primarily motivated by the relative advantages of technologies, particularly operational efficiency (7 respondents), improvements in product quality (5), reductions in resource consumption (4), extended shelf-life (3), and access to new markets (3). For example, Companies 16 and 17 adopted pasteurization technologies to enhance efficiency in juice production. Company 13 was driven by quality improvement and resource savings to introduce energy-efficient equipment in wine production, reducing energy use and preservatives while marginally improving product quality. Company 2 outsourced cold-storage facilities to extend shelf-life and enable entry into export markets.

SMEs reaching medium BMI levels reported a more heterogeneous set of drivers, with market opportunities (7 respondents) and product quality improvements (5) most prominent. For instance, Company 10 targeted emerging health-oriented niches, while Company 6 introduced aquaponic systems to improve the quality of vegetables and fish. Additional drivers included productivity gains (3), academic knowledge (2), and customer requests (2). Company 26 implemented a scalable fig-processing line to address customer requests (current production is insufficient); Companies 4 and 8 leveraged academic expertise to explore identified commercial opportunities aligned with market trends; and Company 25 modified dried-tomato recipes to respond to customer requests for a healthier product alternative.

In contrast, SMEs with complex BMI levels were typically driven by combinations of sustainability-orientation (4 respondents), academic knowledge (4), resource-efficiency objectives (4), and product-quality improvements (3). Sustainability-oriented SMEs such as Companies 3 and 5 aimed to attract environmentally conscious consumers while reducing food waste by valorizing food residues and fully utilizing all animal meat. Microgreen-focused Companies 33 and 34 similarly combined market expansion with quality enhancement and efficiency gains.

3.4.2.2. Barriers

Respondents most frequently reported technical barriers and shortages of knowledge and skills (15) as the main obstacles during technological implementation and scaling. These challenges were particularly salient in physical production systems based on advanced or novel technologies, where SMEs struggled to operationalize equipment, calibrate parameters, ensure reliability, and meet food-quality standards. Company 4, for instance, encountered difficulties in replacing animal-based ingredients with plant-based alternatives while preserving taste and texture, whereas Company 10 faced persistent shelf-life instability across production batches.

Although most technical problems concerned physical systems, digital technologies also generated bottlenecks in several cases. Company 5 experienced repeated platform failures during demand peaks and severe logistical coordination problems following pre-sales of meat boxes. Company 11 similarly confronted major hurdles in developing pruning-waste recycling solutions under regulatory pressure. In the absence of established industry routines, the SME had to design new production procedures, substantially prolonging the transformation process. Such bottlenecks proved particularly burdensome for micro-enterprises and young firms, whose limited workforces were forced to manage routine operations alongside experimental development. Even when outsourcing, these SMEs remained heavily involved in partner coordination and co-design, especially where standardized solutions were unavailable, thereby extending implementation timelines.

Knowledge and skill shortages further slowed transformation trajectories. These deficits stemmed from sectoral inexperience (5 respondents), unfamiliar technologies (10), and recruitment difficulties (6). One SME postponed CRM implementation due to hiring costs, while rural firms struggled to attract qualified staff, resulting in persistent capability gaps during deployment.

Financial constraints constituted another major barrier (14 respondents), limiting investment in capital-intensive technologies and delaying scale-up, particularly among young ventures with restricted revenue bases. Among SMEs pursuing complex BMI, sustainability-oriented offerings sometimes intensified financial pressure when high production costs were not immediately matched by customer willingness to pay.

Market-related barriers were also widespread (12). Firms reported difficulties commercializing technologically enhanced products due to price premiums, saturated domestic markets, low consumer awareness, and unfamiliar BMs. These challenges were most acute for novel value propositions. Company 21, for example, struggled to monetize its farmer–consumer platform

in the absence of established market templates, requiring prolonged experimentation with revenue mechanisms before reaching profitability.

Regulatory obstacles (8 respondents), notably through certification requirements, internationalization procedures, and differentiated food regulations. Administrative complexity and lengthy approval processes delayed commercialization, while the absence of standards for novel technologies such as cold-pressing or pruning-waste valorization further constrained market acceptance.

Finally, high technology costs (4 respondents), when combined with skill shortages and financing constraints, prompted firms to outsource core functions or restrict deployment scope, thereby slowing progress toward full technology assimilation.

Taken together, these barriers directly shaped performance outcomes. Technical problems and capability shortages most often prevented SMEs from achieving stable production, constraining value creation, value proposition development, and targeted product attributes, while the accumulation of market and regulatory constraints limited firms' ability to capture value.

3.4.2.3. Enablers

The enabler analysis focuses on SMEs that successfully advanced technology assimilation and/or BMI during the transformation process. Empirically, this group comprised firms that reached general deployment, several of which did so through outsourcing arrangements, and one case of limited deployment (Company 5) that reported partial success while continuing to refine its digital platform.

Across cases, SMEs introducing relatively simple or widely diffused technologies benefited from shorter learning curves supported by codified knowledge, supplier manuals, and established industry practices. By contrast, SMEs pursuing more complex or novel technologies required prolonged experimentation and relied on a combination of organizational and relational enablers. Four mechanisms proved particularly salient: advanced technological competences acquired through prior education or experience; close collaboration with trusted partners, such as technology providers and cooperatives, for acquisition and training; sufficient investment capacity to sustain deployment and scaling; and learning-oriented organizational cultures, especially among SMEs developing proprietary solutions.

Outsourcing functioned as an enabling mechanism in two distinct ways. Some firms externalized established technological processes primarily for cost-efficiency, whereas younger SMEs outsourced highly customized solutions to develop innovative products. Firms that

achieved their assimilation goals through outsourcing were predominantly those that relied on mainstream processes and could draw on provider expertise, sectoral networks, and effective partner coordination. Even SMEs outsourcing tailored technologies, such as Company 1, benefited from prior relationships and accumulated social capital, which facilitated access to specialized knowledge and reduced coordination costs.

Regarding BMI, successful cases were characterized by strong market knowledge and strategic partnerships that extended organizational capabilities beyond firm boundaries, particularly in commercialization and distribution. SMEs collaborating with customers adapted their value propositions to emerging demand, while firms pursuing complex BMI frequently partnered with universities or research institutes to co-develop novel solutions. Across these cases, innovation-oriented cultures supported risk-taking and iterative experimentation, enabling firms to sustain transformation efforts despite technological uncertainty and high development costs.

Finally, SMEs that achieved positive performance outcomes exhibited strong strategic alignment among technology assimilation, BMI, and market positioning. These firms systematically identified unmet customer needs, translated them into differentiated value propositions, and deployed technologies accordingly. When complex BMI initially constrained value capture due to novelty or cost structures, several SMEs compensated by bundling complementary services (being technology users and providers), repositioning offerings, or leveraging technologies that generated substantial efficiency gains, thereby stabilizing revenues and reinforcing market viability.

3.4.3. Linkages

This section links general patterns in technology assimilation, BMI, their interplay, and performance, along with the key influencing technological, organizational, and environmental conditions.

3.4.3.1. Technology assimilation

Our cross-case analysis reveals a configurational logic in which technological, organizational, and environmental conditions jointly shaped both the process and ultimate levels of technology assimilation. Technological attributes such as complexity, novelty, and cost interacted with organizational characteristics, including firm age, size, product focus, and technological capabilities, as well as with environmental conditions such as information availability and third-

party support. Together, these conditions influenced the pace of assimilation, the barriers encountered, and the level and proficiency firms could reach.

General deployment (24 SMEs): Most firms in this category are incumbent (17) and have largely integrated mainstream technologies, such as pasteurization systems, storage chambers, and tractors. These technologies typically enabled relatively smooth assimilation processes that required limited or no product redesign or external support. In three cases, however, SMEs deployed technologies that were neither cutting-edge nor fully standardized, such as aquaponic systems or energy self-sufficiency equipment for wine preservation, which necessitated targeted assistance from technology providers.

By contrast, four SMEs introduced highly novel field-specific technologies, including agricultural sensors and microgreen-growing systems. Limited market maturity and the absence of specialized suppliers compelled these SMEs to pursue incremental implementation paths, characterized by experimentation and in-house capability development. In such cases, strong internal technological and innovation competences substituted for weak external support. Conversely, SMEs with fewer in-house skills but greater financial resources accelerated assimilation by purchasing external expertise and implementation services.

Despite these heterogeneous paths, all SMEs in this category ultimately reached general deployment through internal development of technological functions. Integration times varied systematically with technological scope and application. Manufacturing-related technologies, such as production-line reconfigurations, required longer stabilization periods due to their complexity and stringent product requirements, whereas digital platforms or standardized food-processing technologies were assimilated more rapidly. Financial resources further conditioned speed: firms with substantial internal capital, cooperative backing, or external funding progressed faster, while those relying on incremental investments experienced protracted trajectories.

Outsourcing (9 SMEs): Outsourcing was concentrated among young and micro-enterprises facing high investment requirements and limited technical expertise. For new ventures, it functioned primarily as an entry strategy, whereas older SMEs deployed outsourcing as a stable organizational arrangement to manage capital constraints. The level of technological proficiency ultimately attained depended on product novelty, partnership duration, and SMEs' capacity to orchestrate external providers while integrating outsourced activities into internal routines. Overall, incumbent firms more frequently reached higher proficiency levels, benefiting from accumulated relationships and established supplier networks.

Limited deployment (3 SMEs): Limited deployment resulted from unresolved technical problems and knowledge gaps associated with scaling innovative products from laboratory or craft settings to industrial production, as well as from the complexity of logistics systems that still required iterative refinement.

Commitment (2 SMEs): Two SMEs remained at the commitment stage due to financial constraints, shortages of skilled personnel, and limited managerial time, thereby delaying full implementation.

Discontinuance (1 SME): In the single case of discontinuance, the firm achieved the desired product quality through HPP, yet high operating costs, weak market acceptance, and regulatory uncertainty undermined commercial viability and ultimately led to technology abandonment.

Table 10 summarizes the main configurational patterns associated with these technology assimilation outcomes.

Table 10: Key features observed related to technology assimilation level

Level of technology assimilation	Key features
General deployment	- **Type of company:** mainly incumbent - **Type of technologies:** mainly mainstream technologies - **Attainment of technological proficiency:** All companies within this category achieved proficiency. The time required for assimilation depends on technological aspects (costs, innovativeness, complexity, and the stage at which the technology is applied), organizational aspects (the organization's ability to invest, the product to be produced, and its technological and innovation capabilities), and environmental aspects (the availability of information and support).
Outsourcing	- **Type of company:** mainly micro and/or new companies - **Type of technologies:** mostly technologies applied to novel food products that are costly or need to be tailored - **Attainment of technological proficiency:** the outsourcing is mainly due to organizational barriers (lack of resources – financial, human, time, physical, and knowledge) and/or technological barriers (high cost). The attainment of desired outcomes in outsourcing is facilitated when companies are experienced in the market, leveraging accumulated knowledge and social capital.
Limited deployment	- **Type of company:** mainly micro - **Type of technologies:** mostly technologies applied to produce innovative food offerings - **Attainment of technological proficiency:** still not fully achieved the expected technological outcomes due to the time required for the scale-up and complex logistics, and organizational barriers such as technical barriers, lack of knowledge, skills, and financial resources.
Commitment	- **Attainment of technological proficiency:** Constrained by the recentness of adoption decision, technological barriers (cost and complexity), and organizational constraints (constraints in financial resources, human resources, skills, and knowledge).
Discontinuance	- **Attainment of technological proficiency:** The only case that achieved technological proficiency, but environmental barriers (lack of market acceptance, difficulty selling the product, lack of regulations) and technological barriers (high cost) led to discontinuance.

3.4.3.2. BMI

In the BMI process, the complexity and time required to implement changes, adapt business practices, and capitalize on innovations are closely tied to the BMI level observed across the identified ten transformation groups (see 3.4.1). Simpler BMI level trajectories typically involved internal limited and faster adjustments, whereas more complex BMI configurations disrupted prevailing practices and required broader reconfiguration times due to changes across multiple value elements. Although such complex trajectories entailed higher execution risks and longer payback periods, they also exhibited greater upside potential and faced less direct competition. In contrast, SMEs operating at simple BMI levels tended to achieve incremental improvements aligned with sector norms, with limited scope for competitive differentiation.

Cross-case comparison shows that BMI outcomes emerge from recurring configurations of conditions, including the type and application of technology, the drivers, the innovativeness of the value proposition, and organizational-level attributes such as age, supply-chain position, and resource endowments.

The type and application of technology played a central role in shaping disruptive potential. Digital platforms, for instance, enabled BMs such as crowdfunding meat purchases or direct farmer-to-consumer systems that restructured traditional supply chains. These innovations required SMEs to develop new relational and logistical arrangements, while customers adapted to trade-offs, such as longer wait times for meat orders (Company 5) or reduced convenience of one-stop shopping (Company 21). In return, consumers gained access to fresher and more sustainable products while supporting farmers and reducing food waste.

Supply-chain position further conditioned BMI trajectories. SMEs with simple BMI levels, typically farmers or processors, used technology primarily to enhance efficiency within existing roles. Medium-BMI SMEs, most often food processors, modified product formulations or introduced new production lines. By contrast, complex-BMI SMEs frequently innovated in multiple stages of the value chain, acting simultaneously as processors and service providers, or intermediaries, or reconfiguring chain structures through circular production systems with waste-repurposing logics.

The foundational business idea underpinning the value proposition proved equally consequential. Complex BMI trajectories were commonly rooted in disruptive concepts such as shortening supply chains, recombining actors, or embedding sustainability through resource reuse and waste reduction. Simpler BMI pathways, in contrast, were largely driven by the exploitation of technological advantages within established industry standards.

These three BMI levels can therefore be characterized as follows.

Simple BMI (13 SMEs) primarily comprised incumbent SMEs introducing conventional technologies to improve value creation through efficiency gains.

Medium BMI (14 SMEs) included mainly new or incumbent processors responding to market opportunities or customer requests through product reformulation and process innovation.

Complex BMI (10 SMEs) involved SMEs reconfiguring all value elements through disruptive business concepts and/or cutting-edge technologies driven by the identification of innovative market opportunities and/or academic knowledge, often pursuing either supply-chain disruption or technological leadership through service provision and academic collaboration.

Table 11 synthesizes these BMI configurations and the associated conditions.

Table 11: Patterns of the level of BMI

Level of BMI	Value element affected	Drivers	Technologies applied	Key feature
Simple (changes in one value element)	**Value creation** - Energy savings - Less waste - Increasing the shelf life - Productivity increases - Increased production - Easier food processing **Or** **Value capture** - New revenue streams by promoting products online	Relative advantages of technologies (increased productivity, reduced waste, and lower resource consumption)	Mostly standard technologies are applied in food processing for efficiency purposes (changing value creation), or digital technology applied for promoting food products (changing value capture)	Mainly incumbent SMEs (farmers and processors) using conventional technologies to produce mainstream products
Medium (changes in two value elements)	**Value creation** - Changes in the production lines - New partnerships for production - Collaboration with customers **And** **Value proposition** - New products - New flavors - Fewer chemicals and additives - Local and fresh production - Healthy products	Identification of customer demands and/or direct customer requests	Mostly food processing technologies applied to change food products or developed to create new food products compared to existing ones in the market	New or incumbent SMEs (food processors) using food processing technologies to create innovative products that meet new customer demands.

Continuation of Table 11: Patterns of the level of BMI

Complex (changes in all value elements)	**Value creation** - New logistics - New procedures for food processing - Partnerships for co-design - Collaboration with customers And **Value proposition** - Food products with less waste and shortening the food supply chain - New consumer behaviour towards food consumption - Changes in the company's behaviour - New services to support the development of technological solutions for new users And **Value capture** - New ways of selling food - New services (technology provision) - Higher margins	Identification of market opportunities (new trends, sustainable issues, promoting healthy food) and academic knowledge	Cutting-edge technologies in the field, digital technologies, or those that support innovative business concepts, are transforming existing practices in the food value chain.	Mostly new SMEs operating at various points in the supply chain or serving as intermediaries, pioneered the use of technology or introduced innovative practices within the sector

3.4.3.3. Interplay of technology assimilation, BMI, and performance

Our analysis indicates that the interconnections among technology assimilation, BMI, and performance are best conceptualized as interacting in decision-making, implementation, and outcomes. Across cases, decision-making rarely treated technological and business considerations as fully separable. Even in efficiency-oriented trajectories, SMEs anticipated how new technologies would affect production routines, cost structures, and operational input, implicitly linking technical choices to business consequences. This overlap was most pronounced in complex BMI trajectories, where technologies were selected in tandem with novel business ideas or supply-chain logics.

At the same time, early integration was uneven across trajectories. In several cases, decision-making prioritized relative advantages while market-facing considerations such as pricing, certification, and commercialization received limited attention. These imbalances produced prolonged intermediate states in which technological systems functioned, but value capture lagged, contributing to stalled trajectories or discontinuities (Company 9).

During implementation, technology assimilation and BMI processes intersected most clearly in the domain of value creation. Company 11 illustrates this dynamic. Anticipating regulatory

constraints on pruning-waste management, the SME experimented with recycling technologies to develop an internal solution. These trials initially increased workloads due to the limited number of employees, and as they navigated unfamiliar routines and compliance requirements, but over time, the activities were routinized and embedded in production workflows, enabling operational stabilization. Once the technology functioned reliably in-house, the firm extended these capabilities into the BMI domain by developing service offerings related to this solution, reframing its value proposition, and strengthening value capture, drawing on prior relationships to position itself as a provider for other firms facing similar regulatory pressures.

In many cases, particularly in food processing, SMEs first had to stabilize production systems, achieve consistent quality parameters, and meet certification requirements. Only after these value-creation routines had been consolidated did firms expand their transformation efforts to redefine value propositions and develop mechanisms for value capture, helping explain why commercialization frequently lagged behind technological proficiency.

Cross-case comparison further indicates that high levels of technology assimilation were neither necessary nor sufficient for complex BMI. Instead, in a heterogeneous sample such as ours, the type of technology, its application scope, and the innovativeness of the underlying business idea exerted a stronger influence on BM change than assimilation depth alone. Fully assimilating flow pasteurization systems, for example, primarily reinforced existing production logics in Companies 16 and 17, whereas digital platforms and/or circular processing concepts created greater scope for reconfiguring multiple value elements.

Performance outcomes depended on whether SMEs strategically aligned technology assimilation and BMI with organizational capabilities, partner networks, regulatory environments, and market demands. SMEs that coordinated these dimensions early were better positioned to translate operational improvements into commercially viable offerings while balancing short-term stability with longer-term experimentation. Company 2 illustrates such alignment by outsourcing cold-storage technologies to access export markets while sustaining domestic operations, while other firms achieved performance gains through low-disruption technologies that enhanced productivity without major repositioning.

Constraints on value capture affecting performance attainment varied systematically across BMI levels. SMEs operating at simple BMI levels competed in mature markets characterized by limited differentiation and margin pressure, often requiring scale to recover investments. Medium-BMI level SMEs frequently encountered difficulties in communicating modified value propositions or in acquiring customers, delaying market uptake despite technological proficiency. Complex-BMI SMEs faced particularly acute legitimacy challenges when

introducing platform-based or circular models, especially where customer and institutional acceptance evolved slowly. Firms that ultimately improved performance did so through strategic bridging moves, notably by offering complementary services, mobilizing university partnerships, and investing in ecosystem development to sustain revenues while core models matured. These SMEs treated service provision and collaboration as mechanisms for value capture that enabled survival and learning during market formation. By contrast, other complex-BMI SMEs remained in reputation-building and capability-development phases, generating visibility and knowledge but not yet consolidating stable commercial returns.

3.5. Discussion

This study addresses two research questions. RQ1 examines how agri-food SMEs assimilate new technologies, adapt their BMs, and how these processes shape perceived performance. Whereas much SME research has focused on adoption decisions or has treated technology assimilation and BMI as independent analytical domains (Sabatini et al., 2022; Pellegrini et al., 2023), this paper integrates technological transformation outcomes and responds to calls for more process-oriented perspectives on organizational change and innovation (Langley et al., 2013). By cross-classifying 39 cases into ten recurrent configurations, we adopt a configurational logic that highlights how technological transformation unfolds through heterogeneous trajectories rather than converging toward a single dominant pathway.

Among incumbent SMEs, the most prevalent trajectories correspond to efficiency-oriented upgrading, consistent with prior work showing that established SMEs tend to privilege incremental innovation grounded in existing competences (Moeuf et al., 2018). Medium-BMI level trajectories displayed sharper contrasts between incumbents and new entrants. Incumbents often combined internally developed technologies with product-oriented adjustments yet struggled to commercialize these innovations, while younger micro-enterprises relied more heavily on outsourcing when experimenting with sustainability- or health-oriented offerings, in line with studies portraying outsourcing as a mechanism for coping with limited resources and enabling gradual capability accumulation (Priyono et al., 2020).

Complex-BMI levels were concentrated among young and micro-enterprises deploying digital platforms, circular production concepts, advanced processing technologies, or simultaneously acting as technology users and providers. In many of these cases, performance was still emerging, while positive outcomes were primarily associated with service-oriented extensions combined with partnerships that functioned as value-capturing mechanisms. These patterns

resonate with research on sustainability transitions and niche innovation, which highlights the difficulties of scaling novel BMs under regulatory uncertainty, legitimacy deficits, and slow demand formation (Geels, 2002; Markard et al., 2012). At the same time, our findings align with Industry 4.0 and digital transformation studies, which show that SMEs frequently complement technology adoption with service provision, consulting, and solution-oriented offerings to justify investments and stabilize revenues (Müller et al., 2018).

More broadly, by distinguishing ten transformation groups, our analysis aligns with digital transformation research suggesting that SMEs follow differentiated pathways shaped by organizational readiness, prior capabilities, and strategic choices regarding where to concentrate transformation efforts rather than adopting one-size-fits-all approaches (Priyono et al., 2020; Warner & Wäger, 2019). We extend this literature by specifying how combinations of technology and product-service scope, organizational characteristics, level of assimilation, and level of BMI structure these pathways across the agri-food context.

RQ2 examines the conditions shaping these outcomes. Across trajectories, the technology assimilation process and outcomes were influenced more by configurations of barriers and enablers than by drivers, particularly those rooted in organizational characteristics. Incumbent SMEs assimilating mainstream technologies typically progressed more smoothly, whereas younger firms adopting novel or poorly standardized technologies relied more heavily on outsourcing as a transitional learning strategy, reinforcing arguments that interorganizational collaboration plays a central role in SME technology assimilation (Pellegrini et al., 2023).

Barriers strongly conditioned the levels of assimilation ultimately reached. Limited deployment and commitment were associated with unresolved technical problems, scale-up challenges, logistics complexity, and shortages of skills, time, and financial resources, especially among micro-enterprises introducing novel food technologies. These patterns align with post-adoption research, which emphasizes that implementation and routinization, rather than adoption per se, constitute the most fragile stages of technological assimilation (Zhu et al., 2006; Fichman & Kemerer, 1999).

Outsourcing further revealed contrasting dynamics across firm types. Established SMEs mobilized pre-existing supplier and distribution ties to improve efficiency and market access, whereas younger firms relied on external partners as they still developed technologies and relationships, limiting their ability to convert outsourcing into rapid scaling or stable commercialization. This distinction echoes Priyono et al. (2020), who show that partner-based transformation strategies are most effective when firms possess sufficient internal capacity and network capabilities to orchestrate external actors.

With respect to BMI, prior research often suggests that the deeper the level of technology assimilation, the higher the BMI, particularly when digital technologies permeate multiple organizational functions (Bouwman et al., 2018; Nosratabadi et al., 2020; Warner & Wäger, 2019). Our findings partly corroborate this view but refine it by showing that the level of assimilation alone is insufficient to account for BMI levels. Instead, BMI levels covaried with technological scope, strategic intent, and application across value-chain activities. Technologies confined to single functions were associated with a simple level of BMI even when fully assimilated, whereas multi-functional applications supported medium and complex BMI levels.

Moreover, several cases demonstrate that technologies that are not inherently disruptive nevertheless generated complex BMI when recombined with innovative business ideas, novel market positioning, or alternative supply-chain logics. This pattern reinforces arguments that BMI is not technologically predetermined (Teece, 2010; Foss & Saebi, 2017) and aligns with work emphasizing that BM outcomes depend on how firms configure technologies with organizational design and market engagement rather than on technological sophistication alone (Chesbrough, 2010).

Drivers also differed across BMI levels. Simple BMI level trajectories were largely efficiency-driven, medium BMI levels combined quality and market drivers, and complex BMI levels were primarily market-opportunity and knowledge-driven. Consistent with Müller et al. (2018), extensive BMI was thus associated with internal opportunity recognition rather than external pressure, suggesting that strategic intent structured the scope of transformation.

Barriers likewise varied across BMI levels. Simple BMI level trajectories were constrained mainly by margin pressure in mature markets, whereas medium and complex BMI faced legitimacy deficits, regulatory ambiguity, scaling difficulties, and high orchestration demands across partners and markets, echoing sustainability transition research emphasizing institutional uncertainty and slow demand formation (Geels, 2002; Markard et al., 2012). Our findings extend this literature by showing that such barriers interact with technology assimilation processes, amplifying coordination challenges when SMEs pursue novel processing modes in the agri-food context.

Across cases, technology assimilation and BMI appeared as overlapping and mutually shaping processes. At the decision stage, although patterns emerged across BMI levels, SMEs rarely articulated their drivers as either purely technological or purely business-oriented. Even in efficiency-oriented trajectories (simple BMI levels), SMEs framed their drivers in terms of the relative advantages of technologies for improving productivity, quality, or resource use,

suggesting that anticipated business implications simultaneously informed early technology choices. This pattern refines adoption-oriented perspectives that conceptualize drivers as predominantly technology-centred and instead supports work highlighting managerial sensemaking and opportunity framing during early transformation phases (Baden Fuller & Haefliger, 2013; Teece, 2010).

During implementation, technology assimilation redistributed tasks, reconfigured workflows, and introduced new competences, thereby reshaping value creation and constituting an initial layer of BMI. At the same time, a conditional temporal ordering emerged. In most cases, technological proficiency was necessary for product reliability and quality assurance, enabling extensions toward the value proposition and value capture. Yet technological proficiency alone rarely translated into performance when commercialization and legitimacy building lagged behind operational change.

Performance thus depended on how SMEs coordinated technology assimilation and BMI as coupled processes involving learning, organizational reconfiguration, regulatory navigation, partner orchestration, and market building activities unfolding at different speeds. The discontinuance case was particularly instructive in this respect, as it illustrates how technology investment decisions remained tightly intertwined with BM considerations and how partial technical success failed to secure viability when market uptake, regulatory clarity, or cost structures shifted. Rather than isolated failures, such reversals resonate with process perspectives, which emphasize that innovation trajectories are repeatedly reassessed and redirected under environmental turbulence (Snihur & Wiklund, 2019).

The classification further indicates that SMEs often occupy intermediate states characterized by anticipated performance, reputational gains, limited deployment, commitment, or reversal, lending support to accounts that portray transformation as unfolding through provisional equilibria rather than binary success-failure outcomes. These dynamics generated patterned commercial bottlenecks across BMI levels. Simple BMI trajectories built around mainstream technologies encountered margin pressure in saturated markets. Medium BMI configurations associated with novel offerings faced legitimacy and consumer understanding challenges. Complex trajectories were particularly exposed to user acceptance and ecosystem formation constraints.

Beyond managerial capabilities, our findings point to structural tensions between short-term efficiency gains and longer-term investments in uncertain, slow-to-pay-off trajectories, particularly in sustainability-oriented models characterized by certification requirements and nascent demand formation. In this sense, technological transformation unfolded as a sequence

of interdependent strategic choices concerning novel versus established technologies, internalization versus outsourcing, niche versus mainstream positioning, and commercialization timing. In this regard, the cases further highlight the analytical value of examining how decision-making and implementation processes evolve jointly rather than in isolation. They suggest the need for integrative process frameworks that capture how technology selection, operational stabilization, BM experimentation, and market engagement co-evolve over time, especially in resource-constrained SME contexts, where misalignment across these domains can rapidly undermine performance (Pellegrini et al., 2023; de Mattos et al., 2024).

3.6. Conclusions

This study advances understanding of technological transformation in agri-food SMEs by adopting a configurational and process-oriented perspective on how technology assimilation and BMI jointly shape performance. Drawing on 39 cases, we identified 10 transformation profiles that capture recurrent combinations of levels of technology assimilation, BMI, and perceived performance outcomes. These profiles constitute a preliminary typology that explains why SMEs pursuing technological transformation may nevertheless follow divergent trajectories and experience markedly different results.

Our findings generate three central conclusions. First, we show that technology assimilation outcomes are shaped less by drivers than by configurations of technological attributes such as novelty, complexity, cost, and application scope, organizational conditions including firm age, resources, skills, and managerial capacity, and environmental constraints related to partner support, regulatory regimes, and customer acceptance. Second, we demonstrate that BMI levels are primarily structured by strategic intent, the disruptiveness of the underlying business idea, firms' supply chain roles, and the scope of technologies applied, rather than by level of assimilation alone. Third, performance depends on the extent to which SMEs translate technological proficiency into viable value-capture mechanisms through strategic alignment and market-building activities. Across several cases, technological success preceded commercial success, demonstrating that value capture frequently lagged behind value creation, particularly when certification, legitimacy-building, and customer adoption served as binding constraints.

These insights carry clear practical implications. The transformation profiles provide a diagnostic device for managers and support actors to anticipate bottlenecks and tailor

interventions. Rather than applying uniform support instruments, technology providers, cooperatives, and policymakers may design profile-specific responses to address distinct coordination, legitimacy, and commercialization challenges. Efficiency-oriented incumbents may require assistance with market differentiation and margin enhancement. Medium-BMI innovators may benefit from legitimacy-building and commercialization support. Complex BMI pioneers may need help with ecosystem orchestration, regulatory navigation, and demand-side adoption strategies. Outsourcing arrangements likewise emerge as strategic choices whose value depends on whether they function as cost hedges, learning devices, or stepping stones toward capability accumulation.

By extending prior agri-food frameworks derived from systematic literature reviews on sustainability and supply chain reconfiguration (Barth et al., 2017; Nosratabadi et al., 2020), this study contributes empirically grounded, configurational evidence on how technology assimilation, BMI, and performance co-evolve within SMEs. The proposed profiles capture persistent intermediate states, stalled trajectories, and divergent strategic paths that remain largely invisible in conceptual typologies, thereby advancing both agri-food scholarship and broader debates on digital and technological transformation in SMEs.

Moreover, the study makes an explicit contribution to the intersection of technological innovation and BMI research. By tracing how decision-making, implementation, and outcomes unfolded, we empirically bridge domains that have frequently been examined in isolation (Baden-Fuller & Haefliger, 2013; Sabatini et al., 2022). In doing so, we advance a process-oriented understanding of technological transformation (Bachmann & Jodlbauer, 2023; de Mattos et al., 2024).

Finally, several research limitations warrant acknowledgement. The qualitative design limits generalization, the diversity of technologies and organizational contexts limits specific inference, and reliance on self-reported performance may introduce subjectivity. The focus on selected EU contexts may also limit broader cross-regional applicability.

Future research could quantitatively test the proposed typology, examine more homogeneous technological and organizational settings, and adopt longitudinal designs to explore how SMEs migrate between transformation profiles over time. Mixed methods approaches would be particularly valuable for evaluating how evolving configurations of technological, organizational, and environmental conditions shape transformation trajectories.

4

An integrative process framework for technological transformation in SMEs: linking technology assimilation and business model innovation

Chapter 4: An integrative process framework for technological transformation in SMEs: linking technology assimilation and business model innovation

Abstract

Small and medium-sized enterprises (SMEs) are increasingly compelled to embrace technological innovation to improve performance and respond to diverse demands. However, the benefits of new technologies rarely materialize in isolation and instead require a broader technological transformation through which SMEs integrate and exploit them. This transformation involves two interrelated processes: technology assimilation, which enables effective integration and use of technology, and business model innovation (BMI), which allows SMEs to exploit technology-enabled opportunities. Although these processes typically co-evolve in practice, they are often examined separately in the literature, resulting in fragmented insights and limited guidance for SMEs. These limitations are further amplified by the abstract nature of the transformation process and the resource constraints SMEs face. To address these challenges, this study develops an integrative framework that brings technology assimilation and BMI together into a coherent representation of the technological transformation process. The framework is developed through an exploratory conceptual development approach combining systematic and iterative literature analysis with qualitative empirical validation. The literature analysis informed the construction of a four-phase model specifying key activities, inputs, outputs, and tools. Empirical validation is provided through qualitative evidence from the agri-food sector. Retrospective data from 20 EU agri-food SMEs that had already undergone technological transformation, complemented by insights from technology providers, were used to clarify SME-specific conditions relevant to the framework application. The framework was subsequently applied to three agri-food SMEs at early stages of transformation. This application confirmed the coherence of the phased structure and reduced abstraction by illustrating how decisions, activities, and constraints unfold in practice. Overall, the study demonstrates the framework's value as a structured and adaptable reference for understanding and planning technological transformation in SMEs. The paper concludes by outlining limitations and directions for future research.

Keywords
Technological transformation; Technology assimilation; Business model innovation; SMEs; Process framework.

This chapter is under review at *Journal of Economy and Technology* as Camila Silva de Mattos, Giustina Pellegrini, and Geoffrey Hagelaar. An integrative process framework for technological transformation in SMEs: linking technology assimilation and business model innovation.

4.1. Introduction

The importance of technological innovation in the business domain has grown substantially over the past three decades, solidifying its position as a central theme in innovation management research (Akbari et al., 2021). This expansion reflects the growing importance of technological innovation for firms, particularly SMEs, as it is associated with enhanced competitiveness, efficiency gains, and sustainable growth (Popa et al., 2018; Akbari et al., 2021). Its importance has become even more evident as SMEs increasingly rely on new technologies to respond to regulatory changes, intensifying competition, globalization, and market disruptions (Priyono et al., 2020).

Despite this growing attention, research still offers limited, fragmented insights into the organizational changes required for organizations to realize the benefits of new technologies. Prior research increasingly converges on the idea that organizations must undergo a broader organizational transformation, within which two processes consistently emerge as central: technology assimilation[9] and business model innovation (BMI) (Baden-Fuller & Haefliger, 2013; Sabatini et al., 2022; de Mattos et al., 2024). Technology assimilation involves integrating new technologies into an organization's existing systems, processes, and practices to ensure optimal functionality (Zhu et al., 2006; Baird et al., 2017), while BMI enables firms to adjust structures, processes, and value mechanisms to capitalize on opportunities enabled by new technologies (Abdelkafi et al., 2013).

Research evidence increasingly confirms the connection between these processes. New technologies often trigger operational and commercial adjustments; BMI mediates the relationship between technology assimilation and performance; and BMI may motivate decisions on technological investments (Baden-Fuller & Haefliger, 2013; Bouwman et al., 2019; Smajlović et al., 2019). In practice, both processes tend to unfold together, frequently blurring the boundary between where one ends and the other begins.

However, research insights into this interaction remain scattered across separate research streams, and most studies continue to analyze technology assimilation and BMI independently, leaving the broader organizational process through which firms integrate and exploit new technologies only partially understood.

[9] We use technology assimilation as a unifying term for clarity and consistency. Although the literature employs labels such as technology adoption, implementation, and technological innovation, these generally denote specific parts of the process — adoption the decision to acquire a technology, implementation its integration into routines, and technological innovation the novelty it generates. While these terms are sometimes used to refer to the entire trajectory, we use technology assimilation because it most clearly captures the process through which a technology evolves from initial awareness to becoming fully embedded in the firm.

More recently, research on digital transformation has drawn increased attention to the intertwined nature of technology assimilation and BMI (e.g., Warner & Wäger, 2019; Singh et al., 2020). The disruptive features of digital technologies make the accompanying technological and business changes particularly visible and difficult to disentangle, a pattern that, while most evident in digital contexts, also emerges with other types of technologies (de Mattos et al., 2024).

In line with this stream of research and recent studies (e.g., de Mattos et al., 2024; Pellegrini et al., 2023), this paper utilizes the term technological transformation to describe the organizational changes through which organizations integrate and exploit new technologies, encompassing both technology assimilation and BMI. The term builds on the logic developed in digital transformation research, while not being limited to digital technologies, allowing the analysis to extend across a broader range of technological contexts.

Existing studies on the technological transformation process remain limited. Much of the literature continues to emphasize the BMI process, often without explicitly clarifying how it relates to technology assimilation or how the two processes unfold together over time (e.g., Pateli & Giaglis, 2005; Wirtz & Daiser, 2018). These limitations are even more pronounced in the context of SMEs, where both research on the technological transformation process and the conditions under which it unfolds remain constrained (de Mattos et al., 2024). SMEs face increasing pressure to embrace new technologies while operating with limited financial and human resources, skill shortages (Brink, 2017), and restricted access to context-specific tools (Heikkilä et al., 2016). Under these conditions, the lack of clear, process-oriented guidance makes it particularly difficult for SMEs to plan, manage, and navigate the challenges associated with technological transformation.

To address these limitations, the present study develops a comprehensive framework that integrates technology assimilation and BMI into a unified representation of the technological transformation process. Our contributions are twofold: (i) advancing the conceptualization of technological transformation through an integrated process model; and (ii) providing SME practitioners and scholars with a structured and adaptable framework informed by literature and empirical insights. To achieve these objectives, we formulated the following research questions (RQs):

RQ1: What is the current understanding of the technological transformation process in SMEs?

RQ2: How can a conceptual framework be structured to include relevant concepts, phases, and tools, thereby improving the representation of the technological transformation process and supporting SMEs in navigating it?
RQ3: To what extent does the framework's application in SMEs validate its logical coherence, enhance understanding of the process, and reveal additional insights not previously identified?

To address these RQs, this study adopts an exploratory conceptual development approach that integrates literature-based analysis with qualitative empirical validation (Jabareen, 2009). The framework development builds on a systematic review of the SME literature, which revealed limited and fragmented process descriptions and representations. These initial insights were complemented by iterative analysis of additional literature to support the structuring of the framework's phases, underlying logic, and key elements.
The empirical context focuses on SMEs in the agri-food sector, a setting characterized by increasing technological, performance, and compliance pressures (Wang et al., 2024). Qualitative complementary insights were drawn from two SME groups: 20 SMEs that had already completed technological transformation, referred to as volunteer SMEs, which provided retrospective insights; and three SMEs at early stages of transformation, referred to as pilots, in which the framework was applied in an ongoing setting. Insights from technology providers were also used to clarify SME-specific conditions relevant to the framework application.
Developed as a general framework independent of specific technological or organizational contexts, the proposed framework enhances conceptual clarity and cross-context applicability. By specifying expected inputs, activities, and outputs across phases, it renders a previously implicit process more explicit, while empirical application illustrates how the structure can be interpreted and used in practice.
The remainder of this paper is structured as follows: section 4.2 outlines the research method; section 4.3.1 and 4.3.2 presents the results of the content analysis; section 4.3.3 details the proposed framework; section 4.3.4 illustrates its application; and section 4.4 discusses implications, concluding with contributions and directions for future research.

4.2. Method

This study adopts an exploratory conceptual development approach that combines systematic and iterative literature analysis with qualitative empirical validation. Such an approach is appropriate when existing research provides fragmented insights into a complex phenomenon

and lacks integrated conceptual representations (Whetten, 1989; Jabareen, 2009). In innovation and management research, similar approaches that integrate literature analysis with qualitative empirical evidence are well established for developing process models, conceptual frameworks, and analytical tools in under-theorized domains (e.g., Toro-Jarrín et al., 2016; Sousa-Zomer & Cauchick-Miguel, 2017; de Mattos et al., 2018; Moro et al., 2022). Following this logic, the research design comprises four phases, each addressing a specific RQ and detailed in sections 4.2.1–4.2.4.

4.2.1. Identification of research opportunities and definition of research questions

The first phase addresses RQ1 by systematically examining how the technological transformation process has been conceptualized in the SME literature. A systematic literature review was conducted to assess existing descriptions and representations of technological transformation in SMEs, with particular attention to process-level accounts linking technology assimilation and BMI.

Search terms were derived from established reviews in the technology assimilation and BMI literature (e.g., Foss & Saebi, 2017; Ahmad & Siraj, 2018) and complemented with SME related keywords (see section 4.2.2, Figure 6). The search was applied to the titles, abstracts, and keywords of peer-reviewed English-language journal articles indexed in Scopus and Web of Science, covering journals that meet established quality and impact standards (e.g., CiteScore, Source Normalized Impact per Paper, h-index, and SCImago Journal Rank).

The initial search was conducted in late 2020 and updated in early 2022. After screening, 165 articles were retained for analysis. Studies were excluded if they (i) did not focus on SMEs, (ii) did not examine SMEs as technology users, or (iii) did not address either technology assimilation or BMI.

The analysis indicates that, despite a growing body of research under the umbrella of technological transformation in SMEs, explicit and integrated process-level descriptions and representations remain limited. Most studies offer only partial or implicit accounts of how technology assimilation and BMI processes unfold and interact over time. A synthesis of the process-related insights identified in this phase is presented in section 4.3.1. These findings establish the current state of knowledge and reveal a clear gap in existing conceptual representations, motivating the formulation of the following RQs and the subsequent research phases.

4.2.2. Literature selection for framework development

The second phase addresses RQ2 and focuses on selecting literature to support the conceptual development of the framework. While the previous phase mapped how technological transformation has been addressed in the SME literature, the process-related insights available were fragmented and offered limited guidance for structuring a coherent framework representation.

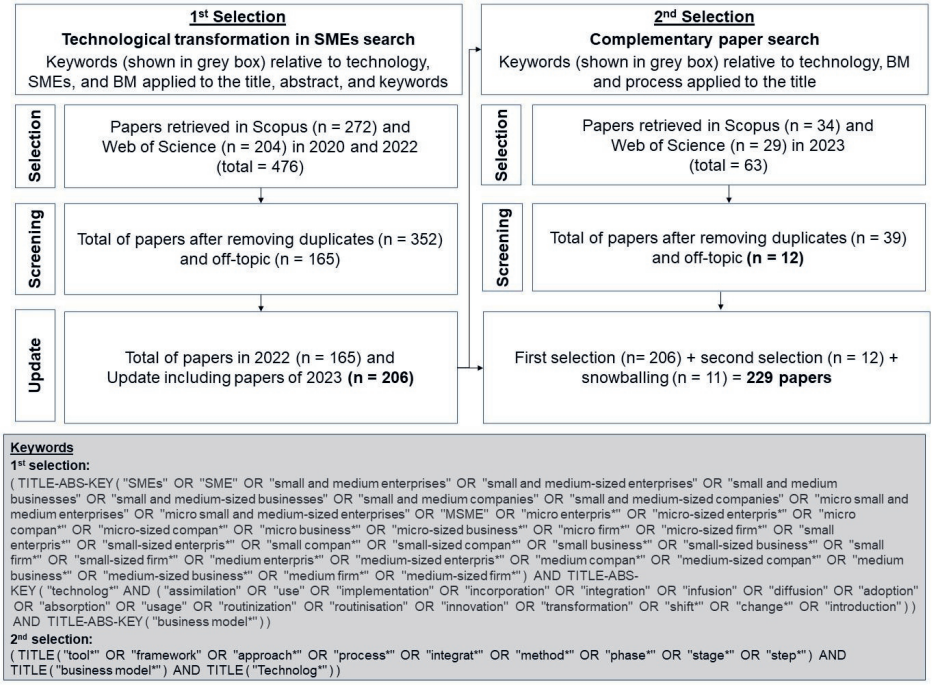
Accordingly, literature selection in this phase was treated as a cumulative, iterative process aimed at identifying studies that could inform the framework's structure, underlying logic, and key conceptual elements. Because framework development unfolded within a multi-year research project, literature selection occurred between 2020 and 2023 across multiple rounds, as summarized in Figure 6.

The initial literature base consisted of the 165 SME-focused articles identified in phase 1 (section 4.2.1), which formed the core scientific foundation on technological transformation in SMEs. In April 2023, this selection was updated by revisiting the same databases with the same keywords and selection criteria used in the systematic review, resulting in the inclusion of 41 additional articles.

Given the continued scarcity of integrated, explicit insights into process conceptualization, structure, or representation in the SME-specific literature, the scope was subsequently expanded beyond the SME context. Keywords related to technology assimilation, BMI, and process were applied to publication titles, maintaining consistency with the same databases, peer-reviewed, and English-language requirements (Figure 6). Articles were excluded if they (i) focused exclusively on BM archetypes, technology benefits, or isolated factors; (ii) lacked explicit insights into the interconnection between technology assimilation and BMI; or (iii) did not provide sufficient detail to inform the development of a structured representation.

Finally, backward and forward snowballing were conducted on the selected studies, resulting in the inclusion of 11 articles. Overall, these rounds yielded a literature base of 229 articles, which informed the content analysis and conceptual development reported in the next phase.

Figure 6: Process of literature selection



4.2.3. Content analysis and conceptual development

This phase addresses RQ2 by analyzing the literature selected in the previous phase to support the conceptual development of the framework. A qualitative content analysis examined how the technological transformation process is described across studies, with particular attention to how technology assimilation and BMI are interrelated and co-developed within it.

In the SME literature, these processes are rarely articulated in an integrated or detailed manner, with relevant insights often presented implicitly and dispersed across empirical descriptions, theoretical arguments, and conceptual discussions. Accordingly, the analysis systematically examined process-related insights across these sources. To strengthen the conceptual grounding, this analysis was complemented by relevant literature on technological transformation beyond the SME context. This analysis focused on identifying recurring structuring logics, including indicative activities, patterns of process progression, interdependencies between technology assimilation and BMI, and the types of information shaping progress across transformation phases (see sections 4.3.1 and 4.3.2).

These insights informed the progressive, iterative development of the framework. Initial phase descriptions guided the conceptual structuring and were refined through repeated discussions

among the researchers, conducted alongside the empirical application of the framework phases, with outputs from one phase informing subsequent ones. This triangulation enhanced clarity and internal coherence while preserving the core conceptual logic grounded in the literature (based on sections 4.2.1 and 4.2.2), culminating in the general framework presented in section 4.3.3.

4.2.4. Empirical validation

To address RQ3, qualitative empirical evidence was collected from agri-food SMEs to examine the framework's coherence, interpretability, and empirical grounding. The empirical research was conducted within a multi-year, EU-funded collaborative research setting involving EU agri-food SMEs, technology providers, and research institutions.

Empirical analysis drew on three qualitative data sources. The first source comprised 20 volunteer SMEs that had already undergone technological transformation. These SMEs provided retrospective insights into how transformation processes unfolded. Data were collected through semi-structured interviews conducted between December 2019 and March 2020, guided by the protocol presented in Table 12. This material informed the empirical application by providing context-specific insights.

Table 12: Volunteer protocol

Sections	Details
General information	Company's name, sector, size, age, role (interviewed)
Technology adopted	Adopted technology and its application
Drivers	Motivations to adopt technologies
Barriers	Challenges in deploying or benefiting from technologies
Changes incurred	Changes due to technology use or new product commercialization
Performances	Perceived performance after technology introduction

The second source comprised three pilot SMEs at early stages of technological transformation involved in the research project, enabling prospective application of the framework in an ongoing setting. A third source of empirical data was technology providers involved in the research project. Three rounds of semi-structured interviews were conducted. The first round of empirical data gathering was conducted in 2019 with founders or CEOs of the pilots (Table 13).

Table 13: 1st interview guide (performed with pilot companies)

Sections	Description
General information	Company's name, activity sector, size, age, role (interviewed)
Current value proposition and differentiation strategies	Solutions offered by the company, along with its competitive strategy
Target market and customers	Customers and markets that the enterprise servers, and the kind of strategies the company use for customer selection
Main promotion channels	How often the company attends fairs/events/presentations/workshops, with or without business partners or community members
Customers relationships	Company's relationship with business partners and customers
Current resources	Physical, intellectual, human, and financial resources to create and deliver value proposition
Key activities	Company operations structure and performance assessment
Internal/external opportunities/threats	Internal/external opportunities/barriers characterizing the business (including technology introduction)
Key business partners and relationships with them	The relationship and kind of information that the company share with its business partners
Community	Main reasons/factors leading to joining this community and the types of information shared within it

The second round, conducted in 2020, involved technology providers and examined the alignment between pilots' needs and available technological solutions (Table 14).

Table 14: 2nd interview guide (performed with technology providers)

Sections	Description
General information about the company	Company's name, sector, size, activities, products/services, customers, collaboration with customers and partners, and mission
General information of the interviewee	Position, time within the organization, commitment (exclusive or not), and expertise
Technologies	Benefits and opportunities offered by the technologies, comparison with existing similar technologies, compatibility, trialability, observability, complexity, adaptability, and overall impact

The third round, conducted in 2023 with both pilot SMEs and technology providers, focused on anticipated barriers, organizational requirements, and changes associated with subsequent stages of transformation (Table 15).

Table 15: 3rd interview protocol (performed with pilots and technology providers)

Sections	Description
Technology assimilation	Technologies tested (in combination or not), relative advantages, expected costs, opportunities, technology requirements, technology performance, piloting stage, costs and barriers
BMI	Changes (expected or incurred) in the BM due to technologies, organizational readiness (organizational requirements to capture/create and deliver new products/services), and barriers

Data triangulation was achieved through the use of complementary materials, including project documentation, technical reports, follow-up exchanges, and structured research inputs. The framework was progressively developed, presented, and applied between 2019 and 2024. Its development and use were embedded in recurring annual workshops involving pilots and project partners (detailed in section 4.3.4).

4.3. Results

4.3.1. Literature insights on technological transformation in SMEs

The content analysis indicates that existing descriptions of the technological transformation process in SMEs are fragmented and unevenly developed. Theoretical contributions tend to concentrate on either the early stages of technological transformation, particularly the factors shaping adoption decisions, or on downstream outcomes such as levels of technology assimilation and BMI, and performance effects (de Mattos et al., 2024; Pellegrini et al., 2023; Sabatini et al., 2022). In contrast, the intermediary phases through which technological assimilation and BMI unfold are typically addressed only implicitly or remain weakly specified. Empirical studies adopting a process-oriented perspective partially address this gap but predominantly rely on retrospective case analyses that emphasize contextual-specific actions (de Mattos et al., 2024). While such studies offer valuable insights into how individual SMEs navigate technological transformation, their focus on specific trajectories limits generalizability and provides limited guidance on how different process elements relate, sequence, and interact across contexts. Comparative studies examining groups of SMEs facing similar barriers, technologies, and contextual conditions offer broader patterns (e.g., Priyono et al., 2020; Pellegrini et al., 2023), yet they still fall short of articulating a coherent, general, and sequential process representation.

To move beyond these fragmented accounts, the analysis examined the main theoretical lenses most frequently mobilized in the SME literature (summarized in Table 16). Rather than attempting to integrate these perspectives into a unified theory, a task rendered impractical by their conceptual diversity, the objective was to identify recurring principles that could inform a structured representation of the technological transformation process. The table and its description will lead towards the recurring principles.

Table 16: Theories used to explain technological transformation

Theory	Description	Emphasis	Main limitations	Examples of references citing the theory
Diffusion of innovation theory - DOI (Rogers, 1995)	DOI aims to explain how perceived innovation characteristics impact adoption decisions	Relative advantage, compatibility, complexity, observability, and trialability	- Overemphasis on the "technological side" - Overemphasis on factors rather than organizational change	Brown and Lockett (2004); Karunagaran et al. (2019); Hussain et al. (2021)
Technology acceptance model - TAM (Davis, 1989)	TAM supports understanding how users arrive at acceptance and usage of specific technology	Perceived usefulness and perceived ease-of-use		Hussein et al. (2019); Bracci et al. (2022); Lim and Baharudin (2013)
Technology Organization and Environment Framework - TOE (Tornatzky & Fleischer 1990)	TOE describes different contexts (technological, organizational, and environmental) that shape the adoption and implementation of technological innovations	Technological, organizational, and environmental factors		Karunagaran et al. (2019); Hussein et al. (2019); Hussain et al. (2021); Mujahed et al. (2021); Bracci et al. (2022)
Absorptive capacity (Cohen & Levinthal, 1990)	Absorptive capacity focuses on the firms' ability to recognize the value of external information, assimilate it and apply this knowledge for commercial purposes	Organizations' capacity to recognize, apply and exploit external knowledge	- Insufficient consideration of external factors - Lack of structured approach and guidance for companies	Müller et al. (2021); Isensee et al. (2020)
Resource-Based View - RBV (Barney, 1991)	RBV is a resource management approach that considers internal resources and capabilities as a source of competitive advantage. It emphasizes the need for organizations to implement strategies that competitors cannot easily replicate by leveraging resources	Leverage companies' resources and capabilities to drive successful innovation		Kollmann and Häsel (2008); Vrontis et al. (2022); Coreynen et al. (2017); Osarenkhoe and Fjellström (2022)
Dynamic capabilities (Teece et al., 1997)	Dynamic capabilities refer to the organizations' ability to adapt and change in response to the dynamic, evolving market	Organizations' capabilities in sensing opportunities and threats, seizing opportunities, and reconfiguring resources		Vrontis et al. (2022); Basiouni (2018); Ibarra et al. (2020); Khurana et al. (2022); Priyono et al. (2020); Coreynen et al. (2017)
BMI (Osterwalder & Pigneur, 2010)	BMI explains how organizations adapt their business by redefining how they create, deliver, and capture value	Changes in business elements	- Overemphasis on the "business side"	Müller et al. (2018); Priyono et al. (2020); Bouwman et al. (2019); Bouwman et al. (2018)

The DOI, TAM, and TOE framework are frequently utilized in SME research to explain technology-related adoption decisions. Despite conceptual differences, these perspectives share a technology-centric orientation, focusing on how technology characteristics, user perceptions, and organizational or environmental conditions enable or constrain adoption decisions. While effective in explaining decision behavior, they provide limited guidance on how SMEs subsequently organize, sequence, and coordinate technological assimilation and BMI activities. Consequently, these theories primarily contribute factor-based insights rather than process-level representations of technological transformation.

Absorptive capacity, the RBV, and dynamic capabilities are commonly used to explain how SMEs build, mobilize, and adapt internal resources during technological transformation. Absorptive capacity focuses on acquiring and exploiting external knowledge, the RBV emphasizes the assessment and strategic deployment of firm resources, and dynamic capabilities highlight sensing, seizing, and reconfiguring activities. While these perspectives shift attention from adoption decisions to organizational capabilities, they remain largely abstract and provide limited insight into how such capabilities are translated into a structured sequence of activities across the transformation process. Consequently, they specify capability requirements rather than offering process-level guidance.

The BMI literature is the most widely applied stream in the selected studies and offers a more explicit structuring of organizational change. By focusing on changes in value creation, delivery, and capture, BMI research provides valuable insight into how firms adapt their BMs in response to new technologies. However, this stream predominantly adopts a business-centric perspective, treating technology as an enabling input rather than as a process that unfolds in parallel with BMI. As a result, BMI literature offers limited guidance on how technology assimilation and BMI co-evolve and are coordinated over time within a unified transformation process.

Synthesizing insights across these main theories, the analysis identified a set of recurring principles, termed critical strategic points (CSPs), that capture how technology assimilation and BMI are configured and coordinated throughout the technological transformation process. Rather than constituting prescriptive steps, CSPs reflect theory-informed structuring principles that indicate what needs to be addressed, aligned, or assessed across different phases of transformation. As summarized in Table 17, these CSPs function as a conceptual bridge between theoretical insights and the process framework developed in Section 4.3.3.

Table 17: Critical strategic points incorporated in our framework based on the theories identified

Critical strategic points (CSP) considered for the framework	ID	Theories
- Incorporation of assessment criteria (e.g., complexity, relative advantage, cost) in the initial phases to guide the technology selection and continuation or not with the subsequent stages	CSP 1	DOI, TAM, TOE
- Emphasis on trialability, allowing technology experimentation before full-scale implementation	CSP 2	DOI
- Consideration of the environmental, organizational, and technological contexts and their interplay (strategic alignment)	CSP 3	TOE
- Incorporation of strategies to absorb technological knowledge and develop new products and/or services accordingly	CSP 4	Absorptive capacity
- Assessment of existing resources to comprehend how SMEs can harness technological transformation	CSP 5	RBV and BMI
- Sensing opportunities and barriers related to technological transformation	CSP 6	Dynamic capabilities
- Formulation of a plan with actions to harness resources for technological transformation and competitive advantage	CSP 7	RBV and dynamic capabilities
- Define the changes based on business elements and consolidated BMI phases	CSP 8	BMI
- Strategic positioning	CSP 9	RBV and BMI

4.3.2. Additional literature insights

While the SME literature provides important insights into technological transformation, it does not offer sufficient guidance on specifying the process's phases and internal structure. To support a more detailed articulation of the framework, the analysis was complemented with process-oriented studies beyond the SME context that provide more explicit representations of technology assimilation, BMI, and their integration.

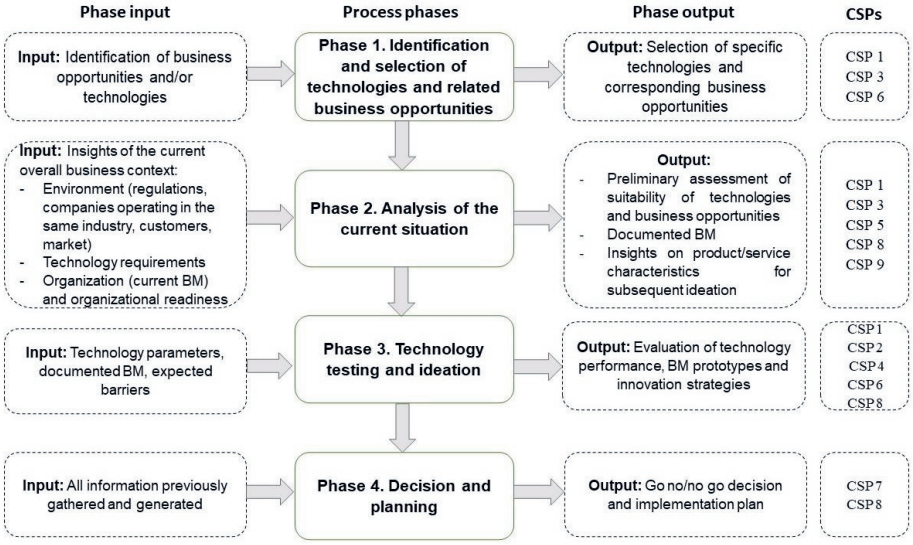
Four contributions were particularly instrumental. Wirtz and Daiser (2018) offer a comprehensive synthesis of BMI phases, providing detailed insights into how BMI unfolds over time. Fichman and Kemerer (1997) present a structured account of the phases of technology assimilation, clarifying the progression from initial awareness to full deployment. Toro-Jarrín et al. (2016) and Pateli and Giaglis (2005) explicitly address the interaction between technology assimilation and BMI, offering conceptual foundations for their integration.

Together with the insights derived from the SME literature, they informed the definition of the framework's phases and their internal logic, which are elaborated in the following section.

4.3.3. Proposed framework

In this section, we present the framework for the technological transformation process, detailing the inputs, outputs, activities, and tools associated with each phase. The phases are grounded in the literature insights and in CSPs (identified in sections 4.3.1 and 4.3.2). Figure 7 provides an overview of the framework.

Figure 7: Framework for technological transformation process



4.3.3.1. Identification and selection of technologies and related business opportunities

Description: Technological transformation begins when organizations become aware of new technologies and/or business opportunities aligned with their strategic goals. This initial awareness may generate interest in pursuing technological transformation and subsequently prompt an evaluation of whether to engage in the process.

In practice, this phase is characterized by two interrelated challenges. First, organizations may become aware of new technologies or business opportunities independently. Investing in technologies without considering market relevance may lead to missed opportunities or financial losses, while focusing on business opportunities without identifying suitable technological solutions may similarly hinder successful implementation. For this reason, aligning technologies and business opportunities from the outset is critical. Second, organizations must assess whether the identified technologies and opportunities are compatible with their internal context, including goals, capabilities, and resources, as well as their external environment, such as market conditions and regulatory requirements. This assessment supports informed decision-making and helps ensure strategic alignment before proceeding further.

Input: Identification of business opportunities and/or technologies

Output: Selection of specific technologies and corresponding business opportunities

Steps, activities, and tools:

Awareness and interest – identification of technologies and/or business opportunities

Awareness of new technologies and business opportunities can arise passively, through exposure to market trends, competitors, and support organizations, or actively, through research and innovation activities. Sector-specific trends often play a central role in identifying relevant technologies. Supporting activities and tools include market research, competitor analysis, internal evaluations, and participation in industry events, conducted independently or in collaboration with technology providers, chambers of commerce (CoCs), or governmental bodies.

Gathering information and aligning technologies with corresponding business opportunities

Organizations often become aware of technologies or business opportunities separately. To avoid misalignment, it is necessary to gather information on both and explore their complementarities. When a business opportunity is identified first, firms may need to search for suitable technological solutions; conversely, when a technology is identified first, its potential business applications must be explored. Research activities and collaboration with technology providers can support this alignment.

Assessment and selection

Following the initial information gathering, organizations evaluate the alignment between technologies and business opportunities by assessing their compatibility and their fit within organizational and environmental contexts. This involves considering technological criteria such as cost and complexity, environmental conditions such as market demand and regulation, and organizational conditions including strategic objectives and available resources. Based on this assessment, firms decide whether to proceed. Technology providers and consultancies may support this phase through workshops or interviews, offering insights to inform strategic decisions.

Background and foundation: The literature suggests that technology assimilation processes typically begin with organizational awareness of new technologies and the emergence of interest in assimilating them (Fichman & Kemerer, 1997; Zhu et al., 2006). In contrast, BMI processes often originate from the identification of business opportunities (Lindgardt et al., 2012; Bachmann & Jodlbauer, 2023). Prior research notes a lack of consensus on the sequence of these activities, suggesting they may unfold concurrently or sequentially, depending on context (de Mattos et al., 2024). Accordingly, this phase integrates the initial activities of both technology assimilation and BMI processes, emphasizing their alignment with each other and with the broader organizational, technological, and environmental contexts. This strategic alignment is consistent with the TOE framework (CSP 3). Assessment criteria derived from

TAM, TOE, and DOI are incorporated to evaluate whether technology characteristics align with organizational objectives and contextual conditions (CSP 1). In addition, the identification of business opportunities enabled by new technologies reflects the sensing capability highlighted in the dynamic capabilities' literature (CSP 6).

4.3.3.2. Phase 2: Analysis of the current situation

Description: This phase focuses on assessing and documenting key information about the overall business context, with two main goals: (i) to ensure the alignment of selected technologies and business opportunities with the overall business context, and (ii) to document the 'stage 0' — before innovation — supporting anticipation of changes, decision-making, and planning. The overall business context includes environmental, organizational, and technological contexts, whose interactions are crucial for assessing potential changes. New technologies require organizational adjustments to facilitate production and commercialization. The complexity of the changes required and the company's readiness influence decisions on whether to proceed and which strategies to pursue. Additionally, ensuring new products/services align with market demand and regulations is essential.

Input: Insights into the current overall business context, including:

- environment: regulations, companies operating in the same industry, customer preferences, market;
- technology requirements
- organization: current BM and organizational readiness

Output: - Preliminary assessment of the suitability of technologies and business opportunities; **-** Documented BM; **-** Insights on product and/or service characteristics for subsequent ideation

Steps, activities, and tools:

Analysis of the organizational context

This step aims to understand how the organization is structured and operates. Document analysis and interviews support documenting the existing BM and facilitate communication with internal and external stakeholders, such as technology providers and project partners. The Business Model Canvas (BMC) is commonly used to represent the BM across nine elements covering value creation, delivery, and capture (Osterwalder & Pigneur, 2010).

Assessing organizational readiness complements BM documentation. Technology audits may be used to evaluate existing infrastructure, capabilities, and systems, identifying gaps relative to the requirements of the selected technologies. These assessments typically consider

implementation needs related to infrastructure, skills, and capabilities, as well as readiness for commercialization, including production, distribution, marketing, and customer reach.

Analysis of the environmental context

The environmental analysis addresses competitive, market, consumer, and regulatory conditions. Competitor analysis helps identify prevailing strategies, trends, and potential challenges faced by firms pursuing similar innovations. Regulatory analysis clarifies compliance requirements related to technology use and enabled products and/or services. Insights into consumer preferences support defining product attributes and marketing strategies aligned with market demand. Activities and tools may include document analysis, interviews, surveys, focus groups, and market studies.

Analysis of the technological context

This step focuses on identifying technological requirements necessary for operational performance and commercialization. Workshops and interviews with technology providers and firms support clarifying functionality, integration requirements, and constraints associated with the selected technologies.

Background and foundation: The analysis of the existing BM is typically situated in the early phases of BMI processes – CSP8 (e.g., Pateli & Giaglis, 2005; Chesbrough, 2007; Wirtz & Daiser, 2018). Assessing existing resources and capabilities aligns with the RBV and dynamic capabilities literature, supporting subsequent reconfiguration efforts (CSP 5). Prior studies also emphasize the importance of assessing customer needs and ecosystem conditions (Amit & Zott, 2012; Frankenberger et al., 2013), reinforcing the relevance of the environmental context highlighted in the TOE framework (CSP 3). These analyses additionally support strategic positioning by identifying differentiating features relative to competitors (CSP 9).

Consistent with DOI, TAM, and TOE, assessing technological requirements is critical for determining whether firms should proceed to testing and implementation (CSP 1). The interaction among organizational, technological, and environmental contexts further shapes readiness for technology assimilation and the development of offerings aligned with external demands (CSP 3). Commercial considerations related to technological innovation are also incorporated, as emphasized in the BMI literature (CSP 8).

4.3.3.3. Technology testing and ideation

Description: This phase combines technology testing and ideation to assess whether the selected technologies can deliver the expected functionality and to explore how they may enable BMI. Technology testing supports evaluating performance, reliability, and feasibility under realistic conditions, while ideation focuses on identifying necessary business changes, potential barriers, and alternative innovation paths. Together, these activities help firms assess transformation complexity and inform subsequent commitment decisions.

Input: Technology parameters, documented BM, expected barriers

Output: Evaluation of technology performance, BM prototypes, and innovation strategies

Steps, activities, and tools:

Technology testing

Technology testing establishes criteria for assessing whether the selected technologies meet expected functional and operational requirements. Comparing expected and actual performance allows organizations to identify deviations that may require technical adjustments, alternative configurations, or technology substitution. Collaboration with technology providers often supports this step by facilitating experimentation, troubleshooting, and optimization under practical constraints.

Ideation of BMs and innovation strategies

Building on the outcomes of technology testing, this step explores how technologies may reshape the BM and identifies feasible innovation paths. Inputs typically include BM documentation, organizational readiness assessments, consumer preferences, and insights from comparable firms. The objective is to articulate concrete BM prototypes and corresponding strategies that address identified implementation challenges. Activities such as brainstorming or pitching workshops support the generation and refinement of BM alternatives, often in combination with tools such as the BMC and BM pattern analysis (Frankenberger et al., 2013).

Background and foundation: Within the technology assimilation literature, organizations progress from awareness and evaluation to trial and, eventually, to commitment decisions (Fichman & Kemerer, 1997). Consistent with DOI, TAM, and TOE, technology testing plays a central role by enabling firms to assess whether technologies offer sufficient business advantages to justify continued investment (CSP 1). This step also reflects DOI's emphasis on trialability before full-scale implementation (CSP 2).

From a BMI perspective, ideation represents a critical phase for translating technological potential into concrete BM configurations (CSP 8). It involves identifying how technologies influence value creation, delivery, and capture, and designing corresponding innovation paths

(Wirtz & Daiser, 2018). Pateli and Giaglis (2005), for example, conceptualize this step as identifying technology-induced changes and required organizational adjustments.

The ideation process further supports the articulation of transformation paths by accounting for barriers and strategies to overcome them, aligning with the sensing dimension of dynamic capabilities (CSP 6). Considerations related to knowledge acquisition and application, emphasized in the absorptive capacity literature, are also integrated to support learning and capability development during this step (CSP 4).

4.3.3.4. Decision and planning

Objective: This phase functions as a decision gate in which organizations determine whether to proceed with, adapt, or discontinue the technological transformation. Building on the outcomes of technology testing and ideation, it focuses on evaluating the feasibility of proposed BM configurations and selecting the set of actions required for implementation. When the transformation is deemed viable, this phase culminates in the formulation of an implementation plan.

Input: All information previously gathered and generated

Output: Go/no-go decision and implementation plan

Steps, activities, and tools:

Analysis of feasibility

Feasibility analysis assesses the anticipated impact, practicality, and economic viability of the proposed BM configurations (Wirtz & Daiser, 2018). This evaluation considers whether expected benefits justify the required investments and organizational changes. Financial feasibility is commonly assessed using tools such as cash flow projections, break-even analysis, and multi-year profit-and-loss estimates.

Decision-making and planning

Decision-making integrates feasibility assessments with the broader set of technological, organizational, and environmental insights accumulated throughout the process. When organizations decide to proceed, a detailed implementation plan is developed to guide execution. Such plans typically specify concrete actions, timelines, milestones, responsibilities, and performance indicators, supporting coordination and resource mobilization during subsequent deployment.

Background and foundation: Within the technology assimilation literature, this phase corresponds to the commitment decision following evaluation or trial, after which firms either

discontinue the initiative or progress to deployment (Fichman & Kemerer, 1997). From a BMI perspective, feasibility assessment and implementation planning represent core steps for translating BM concepts into actionable strategies (Wirtz & Daiser, 2018), reflecting CSP 8.
In addition, this phase operationalizes CSP 7 by emphasizing the formulation of a strategic plan to mobilize and reconfigure resources in line with transformation objectives. A clear decision rationale and implementation roadmap are critical for increasing the likelihood of successful deployment and realizing the anticipated benefits of technological transformation.

4.3.4. Framework application

The application of the literature-based framework aimed to examine its capacity to render the technological transformation process observable, interpretable, and actionable in practice. The sequential phases introduced in the previous section were applied incrementally within a collaborative research setting.

4.3.4.1. Phase 1: Identification and selection of technologies and related business opportunities

Awareness and interest

Pilots' awareness and interest in technological transformation emerged from externally presented technological and business opportunities aligned with their business objectives. These opportunities focused on improving food safety, preserving nutritional quality, and extending the shelf life of minimally processed fruits and vegetables (F&V) through nonthermal food processing technologies. Given their alignment with existing business goals and market trends toward healthy, convenient food products, three agri-food SMEs (pilots) agreed to engage in technological transformation with the support of a research consortium.

Identifying and gathering information on technologies and related business opportunities

An initial portfolio of food processing technologies was identified with the support of technology providers. The pilots engaged in iterative discussions with technology and business experts to evaluate the relevance of these technologies to their specific products, operational constraints, and strategic objectives. This process enabled aligning technological options with both internal and external business opportunities, progressively narrowing the selection to a limited number of viable alternatives per pilot.

Assessment and selection

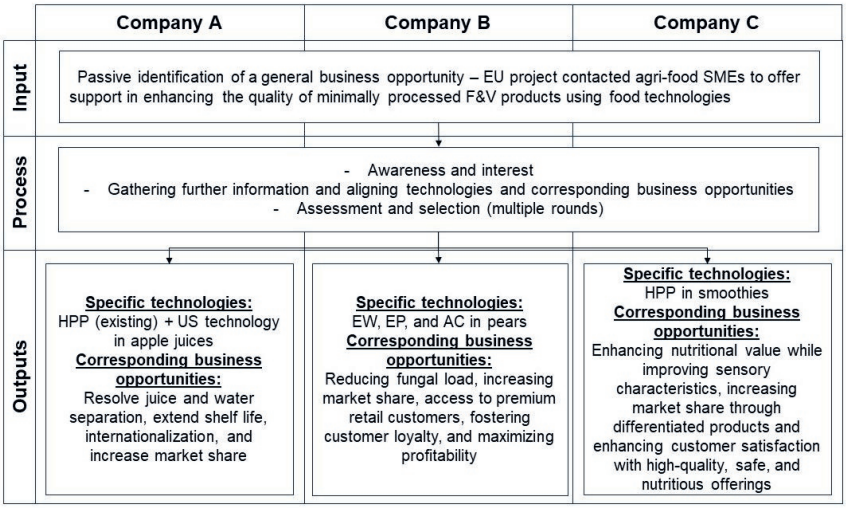
The shortlisted technologies were further assessed through multiple evaluation rounds based on three main criteria: technological characteristics (expected performance improvements and functional benefits); organizational characteristics (business goals and selected product applications); and environmental considerations (perceived consumer trends). At this stage, regulatory and competitive aspects were not explicitly addressed, while practical constraints related to technology availability and technology provider capabilities influenced final selection decisions. Following this assessment, the pilots selected either a single technology or a combination of technologies for further exploration. A detailed overview of phase 1 for each pilot SME is presented below.

- **Company A,** a producer of cold-pressed juices and smoothies, faced challenges related to product stability, particularly water and juice separation in apple juice following High-Pressure Processing (HPP). Although HPP significantly improved shelf life and safety, separation negatively affected product appeal. Moreover, the pilot operated in a saturated domestic market and sought to expand internationally and grow its customer base. Two alternative technologies were initially considered to address these challenges: Ultrasound (US) and Pulsed Electric Field (PEF). The US was identified as a promising solution to improve homogenization by using sound waves to ensure product uniformity, while PEF was expected to improve mixing and extend shelf life. PEF was excluded due to logistical constraints related to geographical distance and service availability. Consequently, the US was selected as the most viable option, given its technical compatibility with existing processes, alignment with the pilot's business objectives, and relevance to market trends favoring healthier beverage products.
- **Company B**, specialized in the production, storage, and commercialization of pears, aimed to eliminate post-harvest fungicide treatments while preserving sensory and nutritional quality. To improve washing and storage processes and enable fungicide-free production, four technologies were initially evaluated: Electrolyzed Water (EW), Electroperoxidated Water (EP), Plasma-Activated Water (PAW), and Active Coating (AC). EW and EP demonstrated strong potential in reducing fungal load while maintaining product quality. PAW was excluded due to limited effectiveness against fungal contamination in pears and logistical constraints. AC proved particularly effective during storage by enhancing product preservation. The final selection consisted of a combination of EW, EP, and AC. This configuration supported Company B's strategic objectives of accessing premium retail segments, strengthening customer loyalty, and increasing profitability. The technology choices were further reinforced by market trends emphasizing healthier, residue-free food products.

- **Company C**, operating in the packaging of F&V products for private-label markets, sought to enhance the nutritional value and sensory attributes (color, texture, and flavor) of smoothies. To achieve these objectives, three technologies were considered: HPP, PEF, and US. Among these alternatives, HPP was identified as the most suitable technology for preserving nutritional quality and ensuring product safety. While PEF and US offered potential improvements, HPP demonstrated superior performance in stabilizing products while maintaining sensory attributes. Moreover, HPP could support differentiation by offering higher-quality, safer, and nutritionally enhanced products, aligning with Company C's objectives of market expansion and increased customer satisfaction, which led to its selection.

Figure 8 summarizes the input, process, and outputs of phase 1.

Figure 8: Summary of phase 1



4.3.5.2. Phase 2: Analysis of the current situation

To assess the current situation, we analyzed the environmental, technological, and organizational contexts in which the selected technologies and business opportunities were embedded. The analysis followed a sequential logic, beginning with the environmental context and then the technological and organizational contexts. This phase aimed to establish a baseline ('stage 0') to inform subsequent activities.

Analysis of the environmental context

Market analysis

Market trends were analyzed to assess demand conditions and growth potential in the pilots' domestic markets and across Europe, supporting decisions on product positioning and market expansion using Statista's market outlook. The analysis focused on sales volume, per capita consumption, pricing trends, and total revenue for comparable product categories.

- Company A: The apple juice market shows stable to slightly increasing sales volumes domestically and moderate growth across Europe. While per capita consumption remains relatively stable in the home market, total revenue trends upward in both contexts, supported by comparatively higher average prices in the domestic market. These conditions suggest opportunities for differentiation through quality improvements and international market expansion.

- Company B: For pear commercialization, revenue projections indicate modest growth in both domestic and European markets, accompanied by relatively stable production volumes. Price increases are expected to be moderate, reflecting incremental value creation rather than structural market shifts.

- Company C: The European smoothie market exhibits consistent growth in sales volume, per capita consumption, and average prices. Similar, though slightly more moderate, trends are observed in the domestic market. These conditions indicate a favorable environment for introducing higher-quality products targeting health-oriented consumer segments.

Regulatory analysis

An initial regulatory screening was conducted to identify certification requirements and potential constraints related to technology use and product commercialization.

- Company A: Export activities require compliance with multiple certification schemes, while the absence of standardized EU regulation for cold-processing technologies introduces uncertainty regarding market communication and consumer trust.

- Company B: Regulatory considerations are primarily related to waste management and certification requirements associated with fungicide-free production, alongside export-related compliance.

- Company C: Similar to previous cases, export certification requirements apply, and the lack of EU-level regulation for cold-processing technologies affects market positioning.

Analysis of consumers' expectations

Project partners assessed consumer perceptions and purchase intentions toward non-thermally processed F&V products through focus groups and an online survey conducted across multiple European countries. As summarized in Table 18, the findings indicate that perceived health benefits, nutritional quality, and extended shelf life positively influence consumer acceptance. However, limited consumer knowledge and concerns about unfamiliar processing technologies remain critical barriers.

Table 18: Summary of the analysis of consumers' expectations

Authors	Focus	Findings
Song et al. (2020)	Consumer perceptions and purchase intentions regarding non-thermally processed F&V products in Denmark, Italy, Serbia, Spain, and Germany through focus groups.	- Consumers appreciated the processing benefits - extended shelf-life, enhanced health and nutrition, and improved hygiene and safety; - Consumers expressed concerns about the impact of new food processing techniques on product quality, safety risks, and environmental impacts; - The lack of consumer knowledge and trustworthy information inhibited consumer acceptance; - Cross-cultural differences: greater interest from participants of Spain, Denmark, and the Netherlands compared to the other counterparts. Recommendations - Building trust in information sources; - Clear communication of safety, benefits, and risks; - Simplifying language (not too technical) to avoid misunderstanding; - Using diverse communication channels (e.g., labelling and social media); - Offering product-tasting experiences; - Tailoring communication strategies according to the cultural context.
Song et al. (2022)	Online survey in Denmark, Italy, Serbia, and Spain, evaluating consumer preferences for non-thermal processing technologies (NTPTs) versus conventional methods in three products: orange juice, iceberg salad, and cherry tomatoes. The survey focused on three attributes: stated benefits (health, nutrition, natural taste, shelf-life), processing information (conventional, NTPT), and price (reference and premium).	- Stated benefits, especially health and nutrition, were the primary driver of consumer choice across all countries and products; - Processing information and price had a similar impact on choices for iceberg salad and cherry tomatoes; - For orange juice, processing information was more influential than price; - Technology concerns significantly inhibited acceptance of NTPT-treated F&Vs, suggesting the need for targeted communication emphasizing health and taste benefits to improve consumer acceptance.

Analysis of companies operating in the same sector

Insights from the 20 volunteer agri-food SMEs were used to identify recurring patterns in technological transformation.

Main changes: Across cases, technological transformation predominantly involved modifications to value propositions and value creation processes, such as the development of improved product formulations and adjustments in farming or processing practices. In contrast, value capture mechanisms remained largely unchanged in most cases. Only a limited subset of SMEs implemented more comprehensive BMI by modifying all three value elements, for instance, through service provision, pricing adjustments, or technology-related consultancy activities.

Process conditions: SMEs that modified their value proposition and value creation typically introduced incremental innovations and relied on established or moderately advanced technologies, resulting in relatively smoother adaptation processes. In contrast, volunteers altering all three value elements adopted more advanced technologies and/or introduced highly differentiated offerings with few market substitutes. While these cases faced greater complexity during adaptation, they also exhibited higher potential for market pioneering. Successful SMEs making complex changes were characterized by one or more of the following: high skill in technology use, support from trusted parties, or substantial investment capacity.

Performance: SMEs reporting positive outcomes demonstrated technological proficiency, achieving targeted product parameters, including shelf life, texture, and flavor. These outcomes were contingent on technology-related attributes (e.g., innovativeness and cost), organizational capabilities (skills and knowledge), and the availability of provider support. Performance gains were further reinforced when technological improvements were translated into clear value propositions that matched market demand, demonstrating strategic alignment between technology assimilation and BMI.

Barriers and strategies: The analysis confirms that barriers play a decisive role in shaping the transformation process, with performance outcomes closely linked to SMEs' ability to deploy appropriate mitigation strategies. The main barriers and corresponding strategies are summarized in Table 19 and inform the subsequent phase.

Table 19: Barriers and strategies for technological transformation

Main barriers	Strategies
Effectively communicating new product formulations to customers Attracting new customers Lack of consumer awareness and/or acceptance	- Investing in marketing and branding (e.g., social media promotion and advertising campaigns) to emphasize the new product benefits; - Building a community around the products; - Develop educational content creation (e.g., info graphs and posts) to explain product benefits; - Events inviting loyal consumers to experiment the new products; - Offer product samples at stores and tasting experiences; - Partnerships with other countries that have demand for innovative food products; - Customer feedback for improving product concepts; - Collaboration with retail partners to promote new products; - Obtain endorsement from a governmental body to reassure consumers hesitant about new products/technologies;
Technical barriers Lack of skills and knowledge Lack of skilled workers	- Provider partnerships and collaboration to acquire expertise and resources to innovate and overcome barriers jointly; - Creation of new roles in the company; - Invest in training programs; - Embrace the new technology and learn its applications through hands-on experience and experimentation.
High technology cost	- Outsourcing enables cost-effective technology use; - Develop an acquisition plan with an extended timeline to ensure adherence to the strategy; - Sharing installations to share costs.

Analysis of the technological context – Technology requirements

Company A required investment in a US machine and limited expansion of production space. Effective operation further depended on targeted workforce training and the recruitment of additional personnel, combining specialized technical expertise with general operational support.

Company B faced moderate technological requirements, primarily related to acquiring a drencher system, equipment for producing EW and EP, and personnel to manage solution preparation and application processes.

Company C confronted substantially higher technological requirements. HPP demanded significant capital investment and specialized skills that were not available internally. As a result, outsourcing HPP services emerged as a viable alternative.

Analysis of the organizational context

Analysis of the current BM

The assessment of the current BMs focused on components most likely to be affected by technological transformation. Consistent with patterns observed among the volunteer SMEs, anticipated changes were concentrated on value proposition (products and customer segments) and value creation and delivery (operations, resources, partnerships, and distribution channels).

The analysis further considered pilots' existing technological and market knowledge as part of organizational readiness. In contrast, value capture mechanisms were expected to remain largely stable at this stage. As pilots were not considering highly complex in-house technologies nor developing entirely new revenue models, anticipated adjustments in pricing or cost structures were limited. Consequently, value capture was not a central focus in this phase. Figures 9, 10, and 11 summarize the current BMs of Companies A, B, and C.

Figure 9: Company A- current BM

Company A - current BM

Value proposition	
Product	**Customer**
Tasty cold pressed smoothies and juices with high quality, functionality, and delightful flavor, produced without additives, preservatives, added sugar, palm oil, dairy, gluten, or soy. These products are designed to boost immunity and energy through a formula that enhances the synergistic interplay of ingredients.	**Target customers** Retailers; gas station; HoreCa (hotels) **Target market** Mostly national Mostly B2B and B2C

Value creation and delivery			
Resources	**Activities**	**Partnerships**	**Distribution channels**
Current knowledge of technology With over a decade of experience in cold pressing, the company has established a strong foundation in innovation, notably through its pioneering adoption of HPP. However, the company lacks knowledge of US technology. **Current knowledge of potential markets** The company's managers possess invaluable insights into market dynamics, customer preferences, and industry best practices.	The smoothies and juices are produced using HPP technology, applying hydraulic pressure to extract pure juice without heat to preserve nutritional content, health benefits, and taste. The company carefully select fruits and vegetables, subjecting them to inspection and washing before gently grinding them to replicate their natural texture.	**- Suppliers** Ensure year-round supply of fresh fruits and vegetables adhering to quality standards - **Network** Ensures product delivery - **Chamber of Commerce** Supports in exploring marketing opportunities	**Indirect channel** Retailers, gas station, HoreCa **Direct channel** E-commerce

Figure 10: Company B- current BM

Company B - current BM

Value proposition	
Product	**Customer**
Top-quality conference pears with the Protected Designation of Origin (PDO). Its standout feature is a distinctive structure that ensures consistent, high-quality production, which is rare for a company of its size.	**Target customers** Retailers **Target market** National B2B

Value creation and delivery			
Resources	**Activities**	**Partnerships**	**Distribution channels**
Current knowledge of technology Scarce knowledge of the three technologies. **Current knowledge of potential markets** The company's managers have a good understanding of industry and market dynamics, as well as customer preferences.	The company uses advanced technology for production and storage in controlled atmosphere conditions, allowing it to preserve about one million kgs of pears. The production process adheres to stringent control procedures set by the Government. These procedures include monitoring cultivation from bloom to harvest, ensuring high fruit quality, minimizing pesticide use through sustainable practices, determining optimal harvest time, employing effective conservation methods during storage, and certifying product authenticity.	PDO and Network distributors	**Indirect channel** Retailers

Figure 11: Company C- current BM

Company C - current BM

Value proposition	
Product	**Customer**
100% natural and organic F&V smoothies and purees, custom-blended to meet client specifications. The products are free from additives and colorants, stabilized solely through thermal treatment, and distributed in flexible packaging.	**Target customers** Retailers, private labels, customers specialized in organic products **Target market** International and national; B2B

Value creation and delivery			
Resources	**Activities**	**Partnerships**	**Distribution channels**
Current knowledge of technology Scarce knowledge of HPP. **Current knowledge of potential markets** Scarce knowledge about potential markets and customer segments.	Standard process flow in the sector for filling flexible pouches, including maintaining a vacuum in each tank to prevent color alteration. The product undergoes heat treatment and pasteurization, then goes through a cooling phase.	Private labels companies, providers, network distributors	**Indirect channel** Distributors and retailers

Preliminary organizational readiness analysis

Organizational readiness was assessed based on perceived technology complexity, compatibility, and costs; technology-related requirements; and existing organizational knowledge.

- **Company A** perceived US technology as compatible, manageable, and affordable. Although the pilot lacked previous experience with the technology, it demonstrated strong innovation, active market sensing, and engagement in industry events, indicating high readiness.

Company B exhibited limited prior knowledge of EW, EP, and AC technologies but anticipated smooth assimilation due to their compatibility with existing processes, low investment requirements, and relative ease of use. Continuous market monitoring and strong sectoral partnerships supported an adequate level of organizational readiness.

- Company C faced substantial readiness constraints. HPP was perceived as complex, capital intensive, and incompatible with existing systems. The absence of internal expertise and limited market knowledge further constrained readiness.

Figure 12: Summary Phase 2

	Company A	Company B	Company C
Inputs	**Environment inputs**		
	Insights on market trends		
	Apple juice sales and revenue are expected to grow domestically and in EU, with higher prices at home country compared to the EU	Pear revenue and prices are expected to rise in the company's country and the EU. Stable domestic production and increases in the EU	Smoothie market in EU and the company's country show increasing sales volumes, rising consumption, and higher average prices
	Insights on regulations		
	Needs certification for exporting and affected by the lack of EU regulations (cold-pressing)	Needs to get more information on waste management regulations and fungi-free certification	Needs certification for exporting and affected by the lack of EU regulations (cold-pressing)
	Insights on companies within the same sector and consumers' expectations are presented in section 4.3.5.2		
	Technological inputs – technology requirements		
	New production shed, US machine, training activities, human resources (marketing skills)	Drencher machine, devices for producing EW and EOW, and skilled human resources	Partnership with a company that has HPP equipment
	Organizational inputs		
	Insights on BM presented in section 4.3.5.2		
	Insights on organizational readiness		
	US technology is perceived as compatible, not complex and not expensive. Experience with innovation and market knowledge	The technologies are perceived as compatible, not complex and not expensive. Engagement in collaborations and aware of market trends	HPP is complex, expensive, and incompatible with existing processes. Lack of market knowledge
Process	**Analysis of the environmental context: market analysis → regulatory analysis → consumer preferences**		
	Analysis of technological context: technology requirements		
	Analysis of organizational context: BM and organizational readiness		
Outputs	***Preliminary assessment***		
	Company A seems well-prepared to introduce US technology	Company B seems prepared to introduce the technologies	Company C seems unprepared to introduce HPP
	Documented BM are shown in Figures 9, 10, and 11 and the strategies for commercialization will be detailed in BMI ideation basing on the insights of consumers preferences and similar company analysis		

In sum, the phase 2 analysis indicated market demand for all selected products and the need for differentiated pricing and communication strategies across national contexts. Regulatory requirements appeared manageable and did not constitute major barriers. Insights on consumer perceptions, comparable SMEs' experiences, technological requirements, and the current pilot

BMs further informed the identification of potential BM changes and ideation. Overall, readiness levels varied across firms — high for Company A, adequate for Company B, and limited for Company C. Figure 12 summarizes Phase 2.

4.3.4.3. Phase 3: Technology testing and ideation

Technology testing was initially conducted at pilots' facilities and subsequently scaled to processing lines, focusing on core product attributes.

- Company A tested US, both standalone and combined with HPP, focusing on shelf life, product stability, and sensory quality. The combination reduced sedimentation and preserved quality, but induced minor taste alterations.
- Company B tested microbial load reduction in pears, with results confirming the effective elimination of post-harvest fungicide treatments.
- Company C compared HPP with conventional thermal processing and found superior preservation of nutritional and sensory attributes when HPP was applied after blanching.

Ideation of BMI

Ideation sessions were conducted to identify required BM changes, barriers, and strategies. BM prototypes were developed using the BMC, complemented by explicit articulation of barriers and innovation paths. The resulting prototypes and innovation paths are summarized below and illustrated in Figures 13–15.

- Company A: US technology-enabled improvements in product stability and shelf life, supporting incremental innovation targeting both existing customers and international markets seeking high-quality juices. Required changes were limited to product attributes and skill development, with no major restructuring of core activities (Figure 13).

Figure 13: Company A prototype

COMPANY A - Prototype

Value proposition		Innovation path	
Product	**Customer**	**Barriers**	**Strategies**
Tasty and functional cold-pressed juices without visual separation and longer shelf life	**Target customers** - Retailers - Private label - Hotel and gasoline station - Small stores - Final consumers **Target markets** National and international	- Technical issue: taste change - Lack of skilled employees - Acquire new customers - Lack of EU Regulation - Lack of consumer awareness - Different certifications for exporting - Consumers mistrust for products produced in countries not known for food quality	- Refining processing and acquiring machinery - Collaborate with technology providers - Collaborate with industry associations and regulatory bodies - Examining the regulations to ensure compliance and facilitate product commercialization - Participation in fairs and food expositions - Marketing strategies emphasizing benefits and processing - Partnership with reputable partners

Value creation and delivery					Value capture	
Tech.	**Resources**	**Activities**	**Partnerships**	**Distribution channels**	**Costs**	**Revenue**
US + HPP (existing)	New production shed, US machine, Human resources (marketing skills)	- Training activities - Applying US after the juicing and HPP after the packaging - Obtaining certification - Participation in fairs - Collaboration with different partners - Obtaining certifications	PDO, technology providers, and stakeholders	International network for exportation Divulgation in media, fairs Using multiple sources: labelling social media, events.	Investments in training, machinery and certifications	Same revenue model, but exploring - Increased direct sale and wholesale - Premium pricing - Increased and different exporting

Innovation path: Technology testing showed that while US technology effectively resolved the separation issue, it also altered taste, a critical product attribute. Addressing this trade-off requires further process optimization or the selection of alternative equipment. Collaboration with technology providers may support refinement; however, persistent sensory degradation would compromise the technology's viability. If adopted, the pilot must strengthen customer loyalty and attract new buyers through targeted communication strategies. Emphasis should be placed on product quality and health benefits, highlighting attributes such as extended shelf life and improved safety through accessible channels (e.g., labeling, social media, and visual materials). Trusted information sources and tasting initiatives can further support consumer acceptance.

Despite the company's established reputation in the cold-pressed juice market, regulatory uncertainty at the EU level limits broader diffusion. Engagement with industry associations and regulatory bodies can support standard-setting and enhance consumer trust. Low awareness of the benefits of cold-pressed processing remains a key barrier, reinforcing the need for educational communication.

Internationalization introduces additional certification-related costs (e.g., audits, documentation, inspections). These challenges require proactive planning, continuous monitoring of regulatory requirements, and incremental market entry strategies that account for cross-country differences in pricing and consumer perceptions. Finally, skepticism toward

products from less-established countries underscores the importance of transparency in sourcing and quality control. Recognized certifications, partnerships with reputable suppliers, and participation in industry events can enhance credibility, facilitate partnerships, and support access to new markets.

- Company B: The application of three technologies aims to innovate the existing pear offering into an innovative, fungicide-free version, targeting existing clients and new premium retailers. The main changes are represented in Figure 14.

Figure 14: BM prototype Company B

COMPANY B - Prototype

Value proposition		Innovation path	
Product	**Customer**	**Barriers**	**Strategies**
Premium quality pears, fungicide-free	**Target customers** Existing Premium retailers **Target markets** National and international	- Technical challenges in managing residues - Obtaining certifications for proving the quality of pears - Obtaining certifications for exporting - Acquiring new customers	- Rigorous monitoring, training, and quality control - Collaboration with technological provider - Collaboration with PDO - Examining the regulations to ensure compliance and facilitate product commercialization - Participation in fairs and food expositions - Marketing strategies emphasizing benefits

Value creation and delivery					Value capture	
Tech.	**Resources**	**Activities**	**Partnerships**	**Distribution channels**	**Costs**	**Revenue**
EW EP AC	- Drencher machine - Machines to produce EW and EP - Human resources (to prepare the EW)	- Application of e EW or EP in the washing - Application of the AC in the post-harvest storage	PDO, technology providers, and distributions network	- Existing network and exploring international network Divulgation in media, fairs - Using multiple sources: labelling social media, events.	Investments in training, machinery and certifications	Same revenue model, but exploring - Increased wholesale - Premium pricing - Increased and different exporting

Innovation path: Technology testing confirmed that the selected technologies effectively replaced post-harvest fungicide treatments. However, it also revealed significant challenges in managing chlorine residues in both drenching water and wastewater. Addressing these issues requires stricter monitoring protocols, dedicated treatment systems, employee training, and reinforced quality control procedures. Collaboration with technology providers and partnerships with PDOs can support process refinement through knowledge exchange, best practices, and targeted training initiatives. As with Company A, certification requirements constitute a significant barrier and require similar compliance strategies. In parallel, attracting new customers remains challenging, reinforcing the importance of participation in industry fairs and sector-specific events to increase market visibility. PDO membership may further enhance

bargaining power and market margins. Communication strategies should emphasize the health and environmental benefits of fungicide-free produce, supported by transparent labeling, social media communication, and clear information on product quality.

- **Company C:** Company C seeks to replace thermal treatment in smoothies with HPP, as testing demonstrated superior performance in sterilization, nutritional preservation, sensory quality (color, texture, and flavor), and shelf life. However, in-house implementation would require substantial investment, specialized skills, and significant operational adjustments. Consequently, the company is considering outsourcing HPP services. Figure 15 shows the Company C BM prototype.

Figure 15: BM prototype Company C

COMPANY C - Prototype

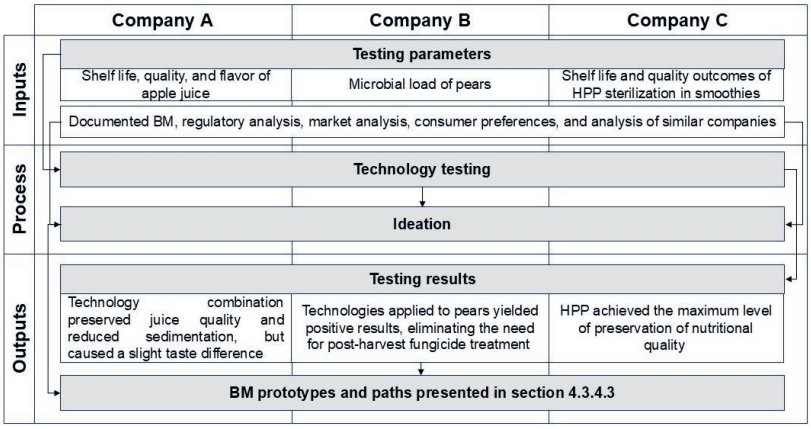
Value proposition		Innovation path	
Product	**Customer**	**Barriers**	**Strategies**
Enhanced nutritional smoothies in flexible packaging with extended shelf life	**Target customers** Existing Private label companies that offer tailored and high-quality solutions that meet the nutritional requirements of various consumers' segments **Target markets** Mostly international	- Technical: build a functional and cost-effective logistic system for technology outsourcing - Difficulty in finding customers interested in specific products - Competitive markets - Different certifications for import/export	- Collaborate with technology providers - Collaborate with industry associations and regulatory bodies - Hiring sales manager and engaging in activities for acquiring customers - Examining the regulations to ensure compliance and facilitate product commercialization - Participation in fairs and food expositions - Collaborate with certified providers

Value creation and delivery					Value capture	
Tech.	**Resources**	**Activities**	**Partnerships**	**Distribution channels**	**Costs**	**Revenue**
HPP	- Human resources (sales and marketing)	- Defining new logistic system - Partnerships with suppliers and technology providers - Obtaining certifications	Certified suppliers technology providers Distributions network	- Existing network and exploring international network - Divulgation with sales manager - Using multiple sources for divulgation	Investments in transport, sales manager, certifications	Same revenue model, but exploring Increased sales for Different private labelling and exporting

Innovation path: Outsourcing HPP operations requires formal agreements with service providers, careful logistics coordination to prevent spoilage, defined processing schedules, and consideration of round-trip transportation costs. Beyond these technical and operational challenges, Company C faces market-related barriers, notably limited brand recognition and constrained market reach, which hinder customer acquisition in a competitive environment. To address these constraints, targeted marketing efforts are needed to communicate the benefits of extended shelf life and enhanced nutritional quality. The company is considering strengthening its commercial capabilities, including using sales agents to support promotion, customer engagement, and market development. Targeting consumer segments that prioritize nutritional

benefits is expected to support market expansion. In parallel, strategic partnerships, exploration of additional distribution channels, and effective management of certification requirements are critical to ensure compliance with EU and international standards. As with other cases, regulatory uncertainty surrounding cold processing may limit broader market acceptance, reinforcing the importance of certification strategies and reliable supplier relationships. Figure 16 summarizes Phase 3.

Figure 16: Phase 3 summary



4.3.4.4. Phase 4: Decision and planning

Feasibility was assessed by combining technology performance outcomes with projected revenue implications. Financial projections focused primarily on variable operational costs, drawing on interview-based estimates and complementary cost analyses. The analysis emphasizes feasibility outcomes rather than commitment decisions, as decision-making extended beyond the study timeframe. The depth of the feasibility assessment varied across cases due to data availability: Company A enabled a detailed financial projection; Company B supported only a qualitative feasibility assessment; and Company C, given limited market and financial information, relied primarily on insights generated in earlier phases.

- Company A: The technology demonstrated strong performance in product preservation and reduction of juice sedimentation. Revenue projections indicate potential growth of approximately 25% in the domestic market and 35–40% in selected international markets. Advancement is conditional on resolving the remaining taste-related issues identified during testing.

- **Company B:** The tested technologies successfully eliminated the need for fungicide treatments. Although detailed financial projections were not available, the company anticipates revenue growth through premium positioning. The fungicide-free value proposition is expected to support customer acquisition, market expansion, and enhanced margins.
- **Company C:** HPP showed clear technological advantages in nutritional preservation and sensory quality. However, uncertainty remains regarding commercialization strategy, target markets, and customer acceptance. While future growth may stem from targeting segments that value nutritional and sensory attributes, further strategic and financial analysis is required before committing.

4.4. Discussion and conclusion

4.4.1. Theoretical contributions

Our literature analysis reinforces a critical gap in the SME technological transformation literature. Prior studies provide insights into decision factors, capability requirements, and BM configurations, but offer limited understanding of how technology assimilation and BMI are coordinated over time as part of a coherent transformation process (Pellegrini et al., 2023; de Mattos et al., 2024). This gap is particularly relevant for SMEs, which increasingly rely on technological innovation to remain competitive while facing resource constraints and limited capacity to manage complex, abstract organizational transformation processes.

This study advances a process-oriented perspective on technological transformation in SMEs. The framework specifies how transformation unfolds through interrelated phases by articulating activities, inputs, outputs, and steps that connect early decisions to downstream outcomes. In doing so, it responds to calls for greater conceptual clarity (Foss & Saebi, 2017) and addresses the critique on the implicit and fragmented process descriptions identified in prior work (de Mattos et al., 2024). By integrating technology assimilation and BMI into a coherent process representation, the study contributes to an emerging but still underdeveloped technology–business intersection, where relevant insights remain dispersed across adjacent streams (Baden-Fuller & Haefliger, 2013; Sabatini et al., 2022).

A further contribution lies in the framework's representation. It provides a general, detailed, and visual, non-technology-specific depiction of technological transformation, supporting analytical transferability across technological contexts, including digital transformation settings characterized by heightened uncertainty and complexity for SMEs (Sagala & Őri, 2024). In line with Jabareen (2009), the framework functions as a conceptual structure that organizes

dispersed insights into a coherent analytical structure, enabling comparison, empirical examination, and refinement.

Finally, the study contributes by introducing CSPs as anchors for the framework's development. CSPs synthesize recurring principles from theoretical streams frequently mobilized in SME research (DOI, TAM, TOE, absorptive capacity, RBV, dynamic capabilities, and BMI). Rather than combining or hierarchizing these perspectives, CSPs translate plural theoretical insights into a parsimonious set of structuring considerations that inform how the transformation process is conceptualized across phases, thereby bridging theory and process representation while preserving theoretical plurality.

4.4.2. Insights gained through the framework application

The framework was applied in a collaborative, externally supported research setting, enabling examination of SME technological transformation under structured external support. Its application demonstrated internal coherence: the proposed phase sequence proved workable across cases and provided a shared reference for structuring analysis, discussion, and decision making.

In a multi-actor setting involving technology specialists and market, consumer, and business researchers, the framework consolidated dispersed technological, organizational, and market-related inputs into a cumulative process logic, reducing process abstractness and supporting more focused coordination and progressively informed decisions among stakeholders and pilot SMEs.

The application also reinforces the idea that technological transformation is context-dependent (Priyono et al., 2020). In this agri-food setting, where food processing technologies are closely tied to product quality and perishability, market and process requirements (e.g., quality preservation and shelf-life objectives) shape screening and testing priorities and the viability of alternative innovation pathways, underscoring the need for explicit attention to contextual conditions in cross-context applications.

External support from trusted actors (i.e., the research partners in the EU research project) influenced both the initiation of the process and the early decision criteria. This contrasts with more typical SME settings, where transformation is commonly driven by external pressures such as regulation, market shifts, or competition (O'Toole, 2003; Müller et al., 2018). The application, therefore, enabled reflection on how pathways may unfold in more autonomous contexts.

While the pilots have initiated transformation through phase 1, independently operating SMEs may enter the process through phase 2 in response to external pressures (Müller et al., 2018). Accordingly, phases 1 and 2 may precede or overlap one another, depending on the context. This flexibility is consistent with prior research showing that technological transformation can be initiated through different entry points and unfold sequentially or concurrently (de Mattos et al., 2024). Thus, the framework emphasizes completing core activities rather than strict adherence to a fixed sequence in the two initial phases.

The external support context also influenced the selection criteria for the technology. Unlike dominant patterns reported in the literature, where cost and complexity strongly constrain SME technology choices (Brown & Lockett, 2004; Mohapatra & Thakurta, 2019), pilots prioritized technological fit and performance potential, as financial exposure and experimentation risks were partially mitigated. This enabled engagement with complex and capital-intensive technologies that would be unlikely under normal market conditions.

Consistent with evidence that constraints vary across stages of technology assimilation and BMI (Santa-Maria et al., 2022), barriers emerged in phase-specific forms. In phase 1, technological screening was constrained by service availability and logistical feasibility, excluding otherwise promising options. In phase 2, constraints were primarily readiness- and requirement-related, especially when technologies were high-capital-intensive, required specialized skills, or were incompatible with existing systems. In phase 3, testing revealed technical and operational barriers not fully visible ex ante, including sensory changes and waste-management requirements. In phase 4, feasibility depended on strategies to resolve these misalignments and on the availability of data to translate into detailed projections.

Progression across phases reflected marked differences in pilots' capabilities and strategic intent. Company A entered the process with a clearly articulated transformation objective and a strong innovation-oriented posture, complemented by robust market and consumer knowledge, as evidenced in the current BM analysis (phase 2). This configuration facilitated early alignment between technology testing outcomes (phase 3) and more advanced feasibility considerations and projections in phase 4. Company B, while less innovation-driven, benefited from solid market and consumer knowledge and from the relatively lower complexity of the selected technologies. These conditions enabled a limited feasibility assessment and the articulation of plausible commercialization paths. In contrast, Company C faced a combination of high technological complexity and capital intensity, together with weaker market and consumer knowledge. These constraints reduced organizational readiness and limited the

translation of testing results into stronger feasibility projections in phase 4, making further progression less likely.

Consistent with evidence that SMEs often rely on external partners, the framework makes explicit where partner management becomes decision-relevant rather than peripheral (Müller et al., 2018; Priyono et al., 2020) and that these are coordination-intensive pathways. In this sense, external support functions both as an enabler and as a source of coordination demands and dependency considerations (Kollmann & Häsel, 2008).

Finally, the process advanced up to the pre-adoption decision/commitment, which helps explain why transformation outcomes may remain partial. Trade-offs identified during testing, as well as capability and coordination requirements emerging during planning, can rationally delay, redirect, or halt progression, reinforcing calls to examine discontinuation and risk in SME transformation as informed outcomes rather than ex post failure narratives.

4.4.3. Managerial implications

The framework provides a structured reference that supports SME managers and stakeholders (e.g., technology providers, consultancies, and government bodies) in navigating technological transformation without having to design the process from scratch. Its primary contribution lies in enhancing analytical clarity by explicitly articulating phase-specific activities, inputs, and outputs, while supporting anticipation of interdependencies between technology assimilation and BMI.

Two implications are particularly relevant. First, the framework highlights the importance of explicitly distinguishing technology testing and ideation from commitment decisions. Early-stage experimentation enables SMEs to surface operational constraints and requirements before investing substantial resources. Second, the framework supports early alignment between technology and business choices, thereby reducing downstream reconfiguration costs and limiting the risk of developing BM ideas that prove infeasible under contextual, organizational, or market constraints.

Importantly, the framework is not intended as a prescriptive roadmap. It is deliberately general and adaptable, allowing for selective or partial application depending on managerial needs and contextual conditions. Even when not applied in its entirety, the framework provides a structured set of considerations that can inform decision-making, support coordination among heterogeneous stakeholders, and enhance reflexivity regarding the assumptions underpinning the technological transformation process.

4.4.4. Limitations and future studies

This study presents three main limitations. First, the framework was applied in a collaborative research setting with substantial external support, which may shape early-phase decision structures and reduce resource constraints typically faced by SMEs transforming independently. Future research should examine how technological transformation evolves without such support. Second, the empirical observation window captured transformation primarily up to the feasibility assessment and pre-commitment stages. Longitudinal studies are needed to follow trajectories through implementation, scaling, and post-implementation BM stabilization, including performance implications over time.

Third, the framework was developed and applied in an agri-food context involving food processing technologies. Future studies should test it across sectors and technology types and examine the adaptation needed. Comparative studies with large firms could further clarify which phase dynamics are SME-specific and which reflect broader transformation patterns.

4.4.5. Conclusion

By synthesizing conceptual insights and translating them into a coherent process framework, this study advances technological transformation research from fragmented, largely implicit explanations toward an integrated process view of how technology assimilation and BMI are coordinated in SMEs. The framework and its empirical validation improve conceptual clarity, support sensemaking and coordination, and provide a foundation for understanding, application, and refinement across contexts.

While the framework was empirically examined in a setting characterized by structured external support, the application indicates that such support primarily affects the sequence of initial activities and technology selection criteria. The underlying phase logic and core process structure remained applicable and adaptable beyond this context, suggesting that the framework is transferable to other SME settings.

5

Discussion and Conclusions

Chapter 5 Discussion and Conclusions

5.1. Scope, context, and logic of the thesis

This thesis advances an integrated understanding of the organizational transformation through which SMEs integrate and exploit new technologies to pursue organizational objectives. Rather than treating technology-related innovation and BMI as loosely connected domains, it conceptualizes technological transformation as a single organizational innovation process in which technology assimilation and BMI co-evolve over time.

By bringing these processes into a unified analytical focus, the thesis makes explicit a phenomenon that is widely observed and frequently acknowledged in the literature, yet rarely examined as a coherent object of analysis. While prior research has generated valuable insights into technology assimilation and BMI, these processes are most often examined separately or linked only implicitly, which limits the ability to understand how technological transformation unfolds as an integrated organizational process.

This perspective provides a more comprehensive representation of technological transformation in SMEs. In practice, assimilating new technologies and adapting BMs are not independent challenges but inseparable components of the same transformation effort. These processes are shaped by organizational, technological, and environmental conditions, by learning processes over time, and by cumulative strategic choices made under contextual constraints.

By adopting this perspective, the thesis contributes to research at the developing interface between technological and business innovation (Baden-Fuller & Haefliger, 2013; Smajlović et al., 2019; Sabatini et al., 2022) by offering a process-oriented understanding of how SMEs manage technological transformation as a whole, rather than as a sequence of isolated decisions, actions, or outcomes. This focus is particularly relevant for SMEs, which are increasingly compelled to introduce new technologies amid uncertainty and pronounced resource constraints to meet diverse demands, such as regulatory pressure, competition, and rapid technological change (Popa et al., 2018; Priyono et al., 2020).

A substantial body of SME research has focused on adoption-related decisions, emphasizing the drivers and barriers that explain why SMEs introduce, delay, or avoid new technologies (de Mattos et al., 2024). This emphasis reflects well-documented realities: financial limitations, time pressures, skill gaps, and risk exposure make commitment decisions regarding new, complex, or capital-intensive technologies especially challenging for SMEs, often leading them to adopt later than larger firms.

However, the decision to introduce a technology represents only an initial moment in a longer, more demanding transformation process. In practice, SMEs frequently encounter difficulties not only in deciding whether to introduce a technology, but in translating that introduction into the outcomes they originally sought. Technological transformation barriers do not end with the decision to start; instead, they evolve as firms must learn to operate new technologies, integrate them into existing processes, coordinate organizational changes, and innovate their business and commercial activities accordingly.

Although some studies extend beyond adoption decisions, research insights remain limited in two main ways (de Mattos et al., 2024). On the one hand, qualitative case studies tend to describe idiosyncratic transformation trajectories, offering rich but context-specific insights. On the other hand, outcome-oriented studies focus on expected performance effects or BM configurations associated with new technologies. As a result, comparatively little is known about what happens between the decision to introduce a technology and the realization of outcomes, namely the organizational actions, decision sequences, and contextual conditions through which innovation initiatives are managed and translated into outcomes. Consequently, both academic research and managerial practice remain strongly oriented toward either adoption decisions or anticipated outcomes, while the intermediate phases remain less explicitly understood.

The agri-food sector offers a particularly informative context for examining technological transformation as an organizational process. Agri-food SMEs operate in environments where compliance with food safety and traceability requirements, product perishability, and increasing environmental and societal pressures related to sustainability and food security make technological transformation increasingly necessary (Musa et al., 2022; Wang et al., 2023; Joshi et al., 2023; ElBeheiry & Balog, 2023). In this context, technologies must not only function technically but also support viable production, commercialization, and value generation under tight operational and market constraints.

To address this phenomenon, the thesis follows a progressive and exploratory research logic. It first maps and articulates fragmented conceptual insights from the literature to consolidate technological transformation as a coherent analytical object across heterogeneous SME contexts (Chapter 2). It then examines how technological transformation unfolds in practice by identifying recurring empirical patterns of processes and outcomes across diverse agri-food SMEs (Chapter 3). Finally, it formalizes a process framework that specifies phases, activities, inputs, and outputs, and validates it through its application to three agri-food SMEs (Chapter 4). By progressively reducing abstraction while maintaining analytical coherence, this thesis

provides a grounded understanding of technological transformation that supports both theoretical development and practical sensemaking across SME contexts.

The following sections discuss the contributions of each chapter in relation to the research questions presented in Chapter 1 and explain how these chapters build upon one another. Subsequently, the theoretical contributions, practical implications, and directions for future research are presented.

5.2. Summary of findings

Research question 1: What is the state of the art in the literature on technological transformation in SMEs?

Research question 1 is addressed in Chapter 2, which assesses the state of the art through a systematic review of 165 peer-reviewed papers (1999–2022) and analytically maps, synthesizes, and structures how technological transformation in SMEs has been approached across the literature. This chapter enables an assessment of what the field collectively knows, where scholarly attention concentrates, and where conceptual and empirical visibility remains limited.

The review reveals two overarching patterns in characterizing the state of the art in this literature: concentration and fragmentation. Concentration refers to the uneven distribution of research attention along the arc of technological transformation. Despite spanning decision-making, the organizational innovation process, and outcomes, existing research predominantly focuses on the decision stage, with a strong emphasis on factors (drivers and barriers) that influence whether or not SMEs introduce new technologies. This emphasis reflects the well-documented tendency of SMEs to lag behind larger companies in introducing technologies, especially costly, complex, or innovative (Brown & Lockett, 2004; Moeuf et al., 2018; Müller et al., 2018; Mohapatra & Thakurta, 2019).

This concentration at the decision stage is accompanied by comparatively limited cumulative insight into later phases of the transformation arc. Substantially fewer studies examine how initial technology-related decisions translate into sequences of organizational actions, how technologies are assimilated beyond early introduction, how interrelated BMI unfold, or how performance outcomes emerge over time. Where process-oriented contributions do exist, they are predominantly grounded in qualitative case studies, which provide rich contextual insight but constrain analytical transferability across SME contexts. Outcome-oriented research, in

turn, tends to emphasize resulting BM configurations or potential technological outcomes rather than realized performance effects and the conditions through which such outcomes are produced.

The concentration pattern identified in Chapter 2 also extends to the dominant analytical approach adopted in prior studies, which largely emphasizes factor-based explanations of technological transformation. Across the reviewed literature, drivers, barriers, and enablers constitute the primary explanatory focus and are most often articulated through the roles of two recurrent actors: owner-managers within the SME and external partners in the surrounding ecosystem.

Within SMEs, owner-managers emerge as the primary locus through which technological transformation is interpreted and enacted. Rather than appearing only as decision makers at the moment of adoption, they are consistently portrayed as shaping strategic orientation, organizational readiness, and the feasibility conditions under which transformation unfolds. Across studies, owner-managers' perceptions, prior experience, and education influence how risks and opportunities are evaluated, which technological options are explored, and which BM elements become targets for change. Internal motivations such as sensing market opportunities or responding to shifts in consumer demand interact with regulatory and competitive pressures to orient transformation trajectories, while prior exposure to innovation activities affects both the decision to engage in technological transformation and its subsequent implementation.

At the same time, the literature attributes an equally prominent constraining role to owner-managers. Limited technological knowledge, uncertainty about economic returns, lack of awareness of available solutions, and negative prior experiences with technology are frequently central barriers to technological transformation. These constraints are intensified by SMEs' restricted access to specialized human capital and by the responsibility placed on owner-managers to absorb risk, interpret complex technological requirements, and orchestrate organizational change. Beyond discrete decisions, managerial action shapes organizational culture toward technological transformation, influencing openness to experimentation, training investments, and the alignment among technology, people, and organizational structures. This body of knowledge, therefore, portrays technological transformation as strongly contingent on managerial sensemaking and the mobilization of managerial capabilities.

A parallel concentration is visible in the treatment of partnerships and external actors. Technology providers, consultants, cooperatives, universities, and public agencies are repeatedly identified as critical enablers of technological transformation in SMEs. Their roles frequently extend beyond technology delivery toward knowledge transfer, operational

alignment, experimentation support, and, in some cases, the strategic adaptation of their own BMs to SME needs, thereby triggering reciprocal BMI across organizational boundaries. These partnerships are emphasized as compensating for SMEs' limited internal capabilities, especially when technologies and related business changes are novel, complex, or capital-intensive.

Yet the same factor-oriented literature also documents the downside of partnership dependence. Collaboration introduces risks associated with partner selection, opportunism, cultural misalignment, and coordination burdens, particularly when technological transformation requires alignment across interdependent value networks or evolving BMs. While external relationships provide access to resources, expertise, and markets, they simultaneously create new dependencies that must be actively managed and that shape the pace, direction, and scope of transformation.

The prominence of owner-managers and external partners reinforces the characterization of technological transformation in SMEs as an organizational process that depends on internal sensemaking and external relational structures rather than on purely technological or business choices. This pattern further supports the argument developed in Chapter 2 that technological transformation requires analytical attention to the contexts in which actors operate, including the interaction between technological attributes, organizational characteristics, and environmental conditions through which organizational processes, resources, knowledge, and relationships are mobilized, negotiated, and coordinated over time.

Fragmentation concerns how technological transformation is analytically partitioned across studies. Most research foregrounds either technology assimilation or BMI as the primary object of analysis, while treating the other as secondary. This pattern appears across different points of the transformation arc, including decision-focused studies, the smaller subset of process-oriented case research, and outcome-focused analyses. In these streams, attention is typically directed toward either technology assimilation or BMI activities rather than toward their joint evolution over time. As a result, insights into how technology assimilation and BMI interact across phases of transformation remain dispersed across separate analytical treatments.

Chapter 2 offers explanations for field fragmentation rooted in its structural characteristics. Research on technological transformation in SMEs spans multiple disciplinary domains, including innovation management, information systems, operations, and entrepreneurship, and draws on diverse theoretical lenses. This multidisciplinary positioning has expanded empirical coverage and conceptual diversity, but it has also limited the development of shared analytical structures and cumulative explanations.

Fragmentation is further reinforced by the context-dependence of technological transformation and the heterogeneity of organizational, environmental, and technological contexts addressed in the literature. Studies examine SMEs with different characteristics (size and age), operating in different industry sectors, and introducing diverse technologies (e.g., digital technologies, Industry 4.0, blockchain, additive manufacturing). These differences give rise to markedly distinct transformation trajectories, varying in complexity, cost, maturity, and organizational implications. As a result, research tends to develop context- and technology-specific explanations that are well suited to capturing patterns of transformation among firms under similar contexts, but less conducive to cross-context generalization and convergence toward integrated accounts of technological transformation as a broader organizational phenomenon.

Finally, fragmentation is reinforced by the field's relative youth. The review shows that most contributions have been published since 2017, indicating that research on technological transformation in SMEs remains in an early phase of consolidation. In such phases, factor-based approaches are a natural starting point, as they help identify the conditions that shape engagement with new technologies.

The patterns of concentration and fragmentation together explain why technological transformation in SMEs is widely addressed in the literature, yet remains weakly integrated at the conceptual level. For academic research, this limits the development of process-oriented explanations capable of accounting for how technological transformation unfolds over time. For practitioners, it results in fragmented guidance that offers limited support for navigating the progression from initial technology-related decisions to sustained organizational transformation.

Although most studies analytically separate or weakly integrate technology assimilation and BMI, Chapter 2 presents recurring conceptual and empirical evidence that they are intertwined throughout the entire transformation arc. At the decision stage, the literature repeatedly signals an overlap between technology assimilation and BMI across decision-making, processual developments, and outcomes, even when studies formally position themselves as focusing on one or the other. The boundary is already blurred, as different factors are shared for technology assimilation and BMI. For instance, pressures from customers and suppliers are often discussed as drivers of technology assimilation-related or BMI-related decisions.

This overlap persists in transformation process accounts, as case studies frequently describe organizational actions that cannot be unambiguously attributed to either technology assimilation or BMI. Changes in key activities, resources, and customer relationships are often reported simultaneously, reflecting how technology-related adjustments and business

reconfiguration unfold together as part of a single organizational transformation process. Consistent with these recurring descriptions, Chapter 2 identifies three process relationships that repeatedly emerge across studies: technology assimilation drives BMI, BMI mediates the relationship between technology assimilation and performance, and BMI can precede and shape subsequent technology assimilation. These relationships reinforce that the literature offers no stable boundary or consistent starting point between the two processes.

Moreover, when studies examine SMEs operating under comparable contexts, technologies, and strategic objectives, the literature suggests an association between the extent of technology assimilation and BMI. Higher levels of technology assimilation, understood as broader deployment across organizational functions or deeper use of technological capabilities, tend to coincide with more extensive adjustments in BM elements (Sabatini et al., 2022). Westerlund (2020) illustrates this pattern in digital contexts, showing that internationally-oriented online SMEs make more extensive use of information systems than their domestically-oriented counterparts, which corresponds to more complex organizational and commercial configurations (i.e., higher levels of BMI).

Against this background and in light of the preceding findings, Chapter 2 responds to research question 1 by concluding that the state of the art is characterized by a field that remains relatively young, analytically fragmented, and strongly concentrated on adoption-related decisions and factor-based explanations, complemented by a smaller body of qualitative research focused on case process descriptions and BM resulting configurations. While these latter contributions provide rich contextual insight, they offer limited cumulative generalization and rarely articulate technological transformation as a single analytical object spanning decisions, processes, and outcomes. At the same time, the chapter positions technological transformation in SMEs as a context-dependent organizational process, conditioned by interacting technological, organizational, and environmental factors and control conditions, with consistent evidence that technology assimilation and BMI are interconnected across the transformation arc.

This diagnosis motivated a step beyond the existing literature by constructing the technological transformation framework presented in Figure 2, which brings together drivers, barriers, enablers, control conditions, processes, and outcomes previously addressed in isolation and reorganizes them along a sequential, visual transformation logic. This structuring makes explicit how technological transformation spans from decision-making to downstream outcomes, clarifying how technology assimilation and BMI are positioned and connected across this trajectory. Importantly, the framework's level of abstraction is consistent with how the

phenomenon is currently articulated in the literature. Given the heterogeneity of technologies, industries, and SME contexts addressed in prior studies, this level of abstraction is necessary to render the phenomenon analytically tractable across contexts while supporting analytical generalization.

By organizing dispersed insights into a coherent and sequential conceptual structure, Chapter 2 establishes the foundation for the subsequent chapters of the thesis, which progressively reduce abstraction while preserving analytical complexity. Rather than introducing new constructs, Chapter 2 reframes existing knowledge by rendering technological transformation a coherent object of analysis and reshaping how research insights can be read, compared, and connected across studies.

Finally, the chapter identifies five research avenues emerging from the review, which are revisited in Section 5.6. Two of these avenues are pursued directly in the following chapters: the empirical examination of transformation processes and outcomes in Chapter 3, and the process-oriented articulation of technological transformation in Chapter 4.

Research question 2: How do EU agri-food SMEs assimilate new technologies, innovate their business models, perceive performance, and what conditions influence their transformation levels and performance perceptions?

Research question 2 is addressed in Chapter 3, which empirically examines technological transformation processes and outcomes, along with the conditions shaping these transformation trajectories, using a multiple-case study of 39 EU agri-food SMEs. Building on the research gap identified in Chapter 2, this chapter responds to the need for empirical patterning by examining how technological, organizational, and environmental conditions interact to shape transformation processes and outcomes across firms.

The empirical design draws on a heterogeneous sample that captures variation in organizational characteristics (size, age, products offered), the types of technologies introduced, and the strategic objectives pursued through technological transformation. This heterogeneity reflects the empirical reality of SMEs and provides a robust basis for examining how technological transformation unfolds across firms operating under different yet structurally comparable conditions.

To operationalize this comparative logic, Chapter 3 adopts a retrospective and abductive analytical approach. It develops a structured way of organizing the observed outcomes of technological transformation, namely levels of technology assimilation, levels of BMI, and

perceived performance outcomes (Figure 4). Building on this outcome-based logic, the chapter introduces a cross-classification (Figure 5) that brings these outcome categories together, enabling the identification of clusters of SMEs in which similar outcome configurations recur. This cross-classification provides a concrete analytical basis for examining patterns of technology assimilation and BMI, both as processes and as outcomes, and their interplay, including how each relates to perceived performance.

By making these patterns visible, the analysis enables an understanding of why certain technological transformation trajectories converge while others diverge, and how these trajectories are associated with underlying combinations of organizational, technological, and environmental conditions that give rise to specific patterns of technological transformation.

The findings show that variation in transformation trajectories is associated with differences in technology characteristics, firm attributes, supply-chain positioning, and access to external support, while remaining shaped by managerial agency and relational structures. The analysis also shows that the interaction among organizational characteristics (firm age, size, and internal capabilities), technological attributes (cost, complexity, innovativeness, and application stage), and the availability of external support primarily shapes technology assimilation strategies and outcomes. For instance, established SMEs adopting mainstream technologies are more likely to achieve general deployment, whereas younger, resource-constrained firms face greater challenges, often relying on outsourcing or experiencing delayed or limited deployment. Across cases, barriers rather than initial drivers emerge as the most influential factor in shaping the level of technology assimilation achieved.

BMI outcomes, in turn, emerge from the interactions among transformation drivers, technology attributes and scope, and organizational characteristics (age, supply chain role, and the novelty of the product or service offering). For example, incumbent SMEs adopting conventional technologies (the majority of the sample) tend to pursue selective adjustments aimed at efficiency and productivity gains, resulting in simpler BMI levels, while younger SMEs more frequently engage in broader BMI aimed at opportunity creation, differentiation, and sustainability-oriented niches. Importantly, the analysis shows that complex BMI is not exclusive to cutting-edge technologies, but can also arise from the creative application of established technologies or from strategic repositioning as solution providers within the value chain.

The cross-classification also makes visible how technology assimilation, BMI, and performance relate to one another. High levels of technology assimilation do not automatically translate into higher BMI levels. For instance, some digital platforms induce complex BMI

levels despite limited assimilation, while mainstream food technologies may reach high levels of assimilation with comparatively narrow BMI implications. These findings challenge implicit linearity assumptions in parts of the literature and underscore the need to conceptualize technological transformation as a configuration-based process shaped by context and strategic intent.

Moreover, the relationship between technology assimilation, BMI, and performance is not contingent on achieving higher levels of technology assimilation. Instead, performance outcomes depend on the extent to which technology assimilation and BMI-related decisions and actions are aligned with the organizational context (e.g., organizational readiness), the environmental context (e.g., market conditions), and the technological context (e.g., complexity and technical performance). Several cases illustrate this dynamic clearly, showing that even when a technology performs well from a technical standpoint, misalignment with market timing or business opportunities can hinder value capture and ultimately undermine economic feasibility.

In line with Chapter 2, Chapter 3 shows that owner–managers play a decisive role in shaping not only whether technological transformation occurs, but also its depth, direction, and coherence across technology assimilation and BMI. Firms with higher BMI levels were typically characterized by owner–managers with prior experience in innovation and/or academic knowledge, and by a proactive role in identifying and interpreting market opportunities to operate in niche or emerging markets. These owner–managers were more likely to pursue proactive transformation paths, aligning technological experimentation with differentiated value propositions rather than limiting change to incremental efficiency improvements. Conversely, SMEs with more conservative owner–managers (most of the sample) were more likely to engage in technological transformation primarily to maintain existing operations, relying on mainstream technologies, implemented internally or through outsourcing when costs were high, and associated with lower BMI levels to operate in mainstream markets.

Chapter 3 also highlights partnerships as a central structuring condition for both technology assimilation and BMI, particularly in cases involving complex, innovative, or capital-intensive technologies. SMEs that reached higher levels of transformation consistently relied on trusted partners to access specialized knowledge, reduce uncertainty, and extend their business functions beyond internal capacities. At the same time, partnerships introduced coordination demands, dependencies, and strategic constraints that shaped transformation trajectories, reinforcing that outcomes emerge from managerial agency and relational structures.

These empirical patterns provided direct input for both the development and the application of the process framework presented in Chapter 4. The findings reinforced the importance of organizational readiness, experimentation before full deployment, and the fit between technology characteristics and business opportunities across the phases of transformation. The cross-classification developed in Chapter 3 further supported the analytical positioning of the pilot companies, whose characteristics aligned with patterns observed among incumbent SMEs adopting food-processing technologies and pursuing medium BMI levels.

Against this background, Chapter 3 responds to research question 2 by demonstrating that technological transformation in SMEs is best understood as a context-dependent organizational process shaped by distinct configurations of organizational, technological, and environmental conditions. By comparing heterogeneous SMEs, the chapter moves beyond firm-specific accounts and shows how recurring combinations of conditions give rise to convergent and divergent trajectories of transformation.

In doing so, Chapter 3 advances the overall thesis by empirically demonstrating how the conditions identified in Chapter 2 interact in shaping recurrent empirical transformation patterns and trajectories across heterogeneous SMEs. By linking abstract conditions to observable outcome configurations, the chapter provides the empirical basis for the process-oriented framework elaborated in Chapter 4.

Research question 3. How can a conceptual framework be structured to include relevant concepts, phases, and tools to represent the technological transformation process and assist SMEs in understanding and undergoing it, and to what extent does its application validate its logical coherence, enhance understanding of the process, and uncover previously unidentified insights?

Research question 3 is addressed in Chapter 4, which develops a process framework for technological transformation in SMEs through an exploratory conceptual development approach that combines systematic and iterative literature analysis with qualitative empirical validation across three pilot cases.

The conceptual development builds on the consolidated body of literature identified in Chapter 2, subsequently updated and expanded to include process-oriented perspectives beyond the SME context. This iterative engagement with the literature reflects not only the exploratory nature of the study but also the state of knowledge in the field of technological transformation.

As established in Chapter 2, existing research provides fragmented and uneven accounts of the technological transformation process.

Chapter 4 advances this diagnosis by suggesting that such fragmentation is not only empirical but also conceptual. The dominant theoretical lenses mobilized in SME research tend to emphasize particular aspects of technological transformation, such as the role of technology characteristics in shaping adoption decisions, organizational capabilities, or changes in BM elements. While these perspectives offer valuable insights into specific aspects of the phenomenon, they provide only limited guidance on how technological, organizational, and environmental considerations are coordinated over time within an ongoing transformation. Consequently, neither individual theories nor their direct combination appear sufficient to articulate what constitutes the transformation process fully or to explain how different conditions interact to shape transformation trajectories.

This latter conclusion motivates conceptual development oriented toward process description and representation, rather than theory testing or further theoretical integration. At the same time, the task addressed in Chapter 4 is analytically demanding, as it involves structuring dispersed insights that operate at different levels of abstraction into a coherent process logic.

To address this challenge, Chapter 4 revisits the main theoretical perspectives used in the literature (Table 16) and extracts recurring structuring logics that cut across otherwise heterogeneous explanations. These logics are formalized as Critical Strategic Points (Table 17), which serve as theory-informed anchoring principles guiding the assessment, alignment, and revisitation of technological, organizational, and business considerations throughout the transformation process. Rather than replacing or synthesizing existing theories into a unified model, these points provide a conceptual bridge between fragmented theoretical insights and a coherent process representation.

Building on these anchoring principles and complementary insights from the literature, Chapter 4 thus contributes by translating fragmented insights into a structured process representation of technological transformation in SMEs, specifying phase-specific inputs, activities, outputs, and decision points, and thereby enabling a more fine-grained analysis of how organizational, technological, and environmental considerations are addressed over time. In doing so, the chapter moves beyond the factor- and control-oriented framework introduced in Chapter 2 (Figure 2) to a structured process framework representation (Figure 7) that captures how technological, organizational, and environmental considerations are addressed over time.

The framework provides an analytical structure that makes explicit how assessment, experimentation, and planning activities are organized and revisited across phases. By

specifying phase-specific inputs and outputs, it reduces the level of abstraction characteristic of much of the existing literature and enables a more fine-grained examination of coordination challenges and decision rationales as technological transformation unfolds.

Importantly, the framework preserves openness to variation in entry points, sequencing, and outcomes. Its value lies not in defining an ideal transformation path but in offering a coherent analytical structure for examining heterogeneous trajectories. This design choice is consistent with the context sensitivity identified in Chapter 2 and with empirical observations that technology assimilation and BMI may overlap, unfold in different sequences, or mutually trigger one another across SMEs.

Framework development and application were further informed by empirical insights derived from both Chapter 3 and the pilot applications conducted in Chapter 4. Although primarily literature-driven, the conceptual elaboration of the framework was shaped by accumulated empirical understanding of how technological transformation unfolds in practice. Prior analyses have shown that transformation outcomes rarely hinge on a single dimension; rather they emerge from alignments and misalignments among technological, organizational, and environmental conditions. Recurrent empirical patterns, such as technologies that function technically but fail to generate value due to weak market alignment, or organizational constraints that limit effective assimilation, sharpened analytical attention during framework development without altering its literature-based foundations.

Accordingly, the framework reflects an effort to render explicit what is often implicitly acknowledged but insufficiently stated in prior research: that technological transformation outcomes depend not only on whether technologies perform as intended, but on how technological choices, organizational capacities, and market logics are continuously aligned and reassessed over time. Within this framing, postponement, redirection, or non-adoption are understood as analytically coherent outcomes of cumulative assessment, rather than as deviations from an expected transformation path.

The empirical application of the framework further demonstrates its analytical coherence and relevance. Across pilot cases, the phase-based structure supported reflection on readiness, alignment, and feasibility while accommodating differences in technological complexity, organizational maturity, and strategic intent. Rather than accelerating adoption or prescribing specific choices, the framework functioned as a shared analytical reference that supported coordination and sensemaking among multiple actors involved in the transformation process.

The application also foregrounds the dual role of partnerships in SME technological transformation. Within the project setting, external partners reduced exposure to

experimentation risks by providing expertise, access to testing infrastructure, and structured support, thereby expanding the set of technologically plausible options and enabling engagement with more complex and capital-intensive solutions than would typically be feasible under purely market-based constraints. At the same time, partnerships did not merely "enable" transformation; they became part of the logic of transformation itself. As transformation progressed, partner availability, interdependencies, and coordination demand increasingly shaped feasibility assessments, timing, and decision rationales. Accordingly, partnership-related considerations functioned as implicit criteria throughout the process, not only as resources supporting action but also as coordination conditions that influence what can be aligned, at what pace, and with which managerial trade-offs.

Differences across pilot trajectories further underline the role of owner-manager agency as a coordinating mechanism. Beyond technological characteristics or resource constraints, progress depended on the owner-manager's capacity to articulate the intent of transformation, mobilize internal attention, and interpret emerging signals from experimentation and market-facing discussions. Cases where owner-managers entered the process with a clearer innovation orientation and a more explicit view of what they sought to achieve were better positioned to translate phase outputs into cumulative assessments and to sustain coordination across actors and activities. By contrast, where strategic intent was less well defined or market knowledge was weaker, the process was more likely to stall at points at which trade-offs became salient, requiring additional alignment work.

In line with the findings from Chapters 2 and 3, the framework was therefore designed as an analytical tool that reflects technological transformation processes as shaped by owner–managers' agency under context-specific conditions, rather than prescribing uniform pathways. Finally, the application highlights that technological transformation in SMEs remains embedded in broader organizational and societal contexts, even under conditions of structured external support. The COVID-19 pandemic constituted a major exogenous disruption that affected not only the coordination and continuity of project support but also the internal priorities of participating SMEs, many of which were simultaneously focused on short-term survival. This reallocation of attention and resources reshaped the pace and direction of transformation activities across cases. While COVID-19 represents an exceptional global disruption, it exemplifies how unforeseen events can alter transformation trajectories even when technological potential and external support are present. In this sense, delays, redirections, or partial progression reflect the open-system nature of SME transformation

processes and reinforce the need to understand technological transformation as a coordinated process unfolding under constraints.

5.3. Main conclusions

Building on the summary of the findings presented in the previous section, this leads to addressing the main research question of the thesis:

How can an integrative framework for the technological transformation process be developed to support and guide the organizational transformation that SMEs undergo when introducing new technologies?

To answer this question, the thesis opens the black box of technological transformation in SMEs by shifting analytical attention away from isolated adoption decisions or anticipated outcomes, and toward the organizational process through which technologies are assimilated, business models are adapted, and outcomes are progressively realized over time. Across its three studies, the thesis demonstrates that technological transformation cannot be adequately captured through exclusively technological or business-oriented perspectives. Instead, it unfolds as a context-dependent organizational process shaped by interactions among environmental, technological, and organizational conditions.

At a conceptual level, the thesis concludes that technological transformation in SMEs is inherently contingent and configurational. The literature review organizes and systematizes fragmented insights, showing that transformation trajectories are conditioned by structural controls such as technology type, firm size, industry, and age, as well as by context-specific drivers, barriers, and enablers, including competitive and regulatory pressures, technology cost and complexity, organizational capabilities, and access to external support. Crucially, these conditions do not operate in isolation. Their interaction shapes not only how technological transformation is initiated, but also how it progresses, stabilizes, or is redirected over time.

The empirical analysis in the agri-food sector refines this understanding by demonstrating how different configurations of environmental, technological, and organizational conditions shape SMEs' experiences with technological transformation. By classifying SMEs into three outcome categories (levels of technology assimilation and BMI, and perceived performance), the thesis identifies recurring transformation patterns rather than idiosyncratic cases. These patterns lead

to the conclusion that SMEs facing similar conditions tend to adopt comparable transformation approaches, even when operating with different technologies or products.

This pattern-based perspective allows the thesis to move beyond firm-level description toward analytical generalization. The findings show, for example, that well-established SMEs introducing conventional technologies to improve efficiency often exhibit limited but focused BM changes, while younger firms pursuing novel products or market opportunities are more likely to engage in more extensive BMI. These findings reflect how technology attributes, organizational maturity, product characteristics, and market positioning jointly constrain and enable transformation trajectories.

A central conclusion of the thesis is that effective technological transformation in SMEs depends on early and continuous alignment between technology assimilation, BMI, and the broader business context. Selecting technology solely on technical potential or expected benefits often leads to implementation difficulties or value capture issues. In contrast, SMEs that explicitly consider organizational readiness, market access, cost structures, and BM implications from the outset are better positioned to translate technological initiatives into meaningful outcomes. This insight is empirically supported by the observation that SMEs that achieve stronger alignment between technology assimilation and BMI decisions and actions report more positive performance perceptions, whereas misalignment is associated with technical setbacks, stalled implementation, or difficulties with monetization.

By integrating these insights, the thesis advances an integrative process framework that supports SMEs in navigating technological transformation as a coordinated organizational process. Formalized in Chapter 4, the framework synthesizes environmental, technological, and organizational considerations into a phase-based structure that clarifies activities, decision points, and interdependencies without prescribing a single transformation path. Rather than offering normative guidance, the framework functions as an analytical device that reduces conceptual abstraction and enables systematic reflection on coordination challenges, trade-offs, and feasibility over time.

The thesis further concludes on the role of key actors in shaping transformation processes. Owner–managers emerge as central coordinating agents who interpret external pressures, mobilize organizational attention, and translate technological experimentation into strategic and commercial decisions. Their capacity to articulate transformation intent, assess emerging information, and balance technological ambition with organizational and market realities strongly influences how far and in which direction transformation progresses. Similarly, partnerships, particularly with technology providers, cooperatives, and knowledge institutions,

play a dual role. They expand SMEs' access to expertise, infrastructure, and experimentation opportunities, but simultaneously introduce interdependencies and coordination demands that become increasingly salient as transformation advances.

Taken together, the three studies progressively advance understanding of technological transformation in SMEs. Chapter 2 consolidates a fragmented literature and establishes a coherent conceptual baseline. Chapter 3 empirically demonstrates how transformation unfolds through patterned trajectories shaped by configurations of conditions. Chapter 4 translates these insights into a process framework that explains how alignment, experimentation, and cumulative assessment structure transformation over time. This progression allows the thesis to move from fragmented, factor-based explanations toward an integrated process perspective that captures technological transformation as an organizational coordination.

Overall, the thesis advances the field by reframing technological transformation not as a sequence of isolated decisions or outcomes, but as a coordinated, cumulative process in which technology assimilation and BMI co-evolve. By explicitly articulating this coordination, the integrative framework provides a stronger analytical foundation for cumulative research and a structured reference for understanding why technological transformation in SMEs often remains partial, iterative, or redirected rather than linear or complete.

5.4. Theoretical implications

Across the three studies, this thesis advances a theoretical contribution by developing a progressive, process-oriented understanding of technological transformation in SMEs. Rather than treating technology assimilation and BMI as isolated, parallel, or sequential phenomena associated with the introduction of new technologies, the thesis conceptualized technological transformation as an emergent organizational process shaped by the interaction of technological, organizational, and environmental conditions over time. This contribution is embedded in a cumulative analytical logic through which the phenomenon was progressively specified, structured, and rendered analytically tractable across chapters.

Consistent with Whetten's (1989) view that theoretical advancement depends on clarity about which constructs are involved, how they are related, and why these relationships matter, the primary contribution of this thesis lies in strengthening conceptual, relational, and process clarity regarding technological transformation in SMEs. In this sense, the thesis contributed by making a previously under-specified and fragmented phenomenon analytically intelligible,

structurally explicit, and systematically examinable, thereby creating conditions for more cumulative, comparative, and process-sensitive research.

A first theoretical contribution lies in the conceptual consolidation developed in Chapter 2. Rather than introducing a new construct or privileging a single theoretical lens, the chapter systematically organizes dispersed insights from heterogeneous research streams into a shared conceptual structure that renders technological transformation visible as a coherent analytical phenomenon (Figure 2). By integrating drivers, barriers, enablers, control conditions, process references, and outcomes within a single representation, the framework brings structure to a field characterized by conceptual dispersion.

Consistent with Jabareen's (2009) view of conceptual frameworks as theory-building devices, Figure 2 does not reduce complexity; rather, it organizes it. It clarifies the scope of technological transformation in SMEs, delineates key analytical components, and establishes a common reference point for cross-study and cross-context comparisons.

Chapter 2 further makes explicit how existing knowledge is unevenly distributed across stages of the transformation process and surfaces assumptions that remain implicit in much of the prior literature. The analysis shows that fragmentation in this field is not accidental, but structurally produced by the intersection of multiple disciplines, technological domains, and empirical contexts, combined with a prevailing focus on early-stage decisions and anticipated outcomes. By making these structural characteristics explicit, Chapter 2 establishes a necessary conceptual baseline for cumulative theorizing. It clarifies where knowledge is concentrated, where gaps persist, and why prior research has struggled to move beyond fragmented, factor-based, or context-specific explanations.

Chapter 3 advances this conceptual foundation by shifting from conceptual organization to empirical patterning. The chapter retrospectively reconstructs trajectories of technological transformation by classifying SMEs according to configurations of outcomes across three categories: levels of technology assimilation, levels of BMI, and perceived performance. This outcome-based classification enables the identification of recurrent transformation patterns across heterogeneous firms, demonstrating that SMEs exposed to similar combinations of organizational, technological, and environmental conditions tend to exhibit similar transformation trajectories.

The key theoretical contribution of Chapter 3 lies in showing that technological transformation exhibits regularities at the level of processes and outcomes that cannot be captured by adoption- or factor-based explanations alone. By tracing back observed outcomes to underlying organizational, technological, and environmental conditions, the chapter explains why certain

decisions are made, in which types of firms and contexts they typically occur, and why specific outcomes emerge from alignment or misalignment among technology assimilation, BMI, and the broader context.

This backward analytical logic resonates with process theorizing as articulated by Langley (1999), shifting attention away from explaining variance in isolated outcomes toward understanding how sequences of decisions, conditions, and constraints combine over time to shape distinct transformation trajectories. Importantly, the classification introduced in Chapter 3 provides an analytical device for moving beyond firm-specific narratives toward patterned explanation. By grouping SMEs that differ in size, technology, and strategic intent but converge in outcome configurations, the classification supports analytical generalization while remaining sensitive to contextual heterogeneity. This suggests that, in more homogeneous samples or more narrowly defined contexts, similar classifications could support even finer-grained characterization of transformation pathways and contingencies.

Chapter 4 builds directly on these insights by formalizing technological transformation as a phase-based process (Figure 7). The resulting framework is not intended as an idealized or prescriptive model, but as a synthesis that translates recurring empirical patterns and plural theoretical insights into a coherent process representation. By specifying phases, activities, inputs, outputs, and decision points, the framework clarifies how technology assimilation and BMI are coordinated over time, rather than treated as parallel or sequential choices.

Figure 7 plays a central theoretical role by reducing analytical abstraction while preserving the inherent complexity of technological transformation. Rather than functioning as a descriptive illustration, the framework constitutes a visual form of theorizing that makes process logic explicit. In line with process-based and design-oriented theorizing, the visual representation specifies how phases, activities, inputs, outputs, and decision points are connected over time, thereby rendering coordination mechanisms and temporal dependencies analytically observable without prescribing a single transformation path.

In this sense, the framework supports theory development not by predicting outcomes, but by structuring how the phenomenon can be systematically examined, compared, and empirically traced across heterogeneous contexts. It directly addresses recurrent critiques in the SME literature regarding the implicit, fragmented, or underspecified treatment of transformation processes by making the underlying process architecture visible and analytically accessible.

More broadly, both Figures 2 and 7 serve as visual conceptual representations that actively contribute to theory building. As emphasized by Whetten (1989), visual representations contribute to conceptual development by delineating construct boundaries, articulating

relational logics, and positioning constructs across levels of abstraction. Similarly, following Jabareen (2009), the figures operate as conceptual frameworks that organize dispersed insights into a coherent analytical structure, enabling alignment, comparison, and cumulative refinement. In this way, the visual representations do not merely accompany the theoretical argument, but constitute an integral component of the theorizing process itself.

Rather than privileging a single theoretical lens, the framework draws selectively on recurring principles across theories frequently mobilized in SME research, including DOI, TAM, TOE, absorptive capacity, RBV, dynamic capabilities, and BMI. This approach preserves theoretical plurality while enabling a coherent process logic. Consistent with design-oriented theorizing, these theories inform how the transformation process is structured and examined, rather than serving as deterministic predictors of outcomes.

Finally, the thesis advances research on technological transformation in SMEs from fragmented, factor-based explanations toward an integrated process perspective. By progressively moving from conceptual consolidation to empirical patterning, and finally to process formalization, the thesis reduces analytical abstraction while preserving the phenomenon's complexity.

5.5. Practical and policy implications

The findings of this thesis indicate that technological transformation in SMEs cannot be effectively supported through generic adoption incentives or technology-centric interventions. Across the three studies, technological transformation consistently emerges as a context-dependent organizational process, shaped by the interaction of technological requirements, organizational capabilities, and market conditions. Consequently, both managerial action and public support mechanisms must move beyond a narrow focus on technology uptake and instead align with the specific conditions under which transformation unfolds.

For SME managers, the central implication is the need to move beyond opportunity-driven or technology-led decision-making toward a structured and reflective assessment of transformation feasibility. The integrated perspective developed in this thesis demonstrates that drivers such as perceived usefulness, regulatory pressure, or market opportunities are insufficient indicators of transformation viability on their own. These drivers must be assessed alongside organizational readiness, internal capabilities, partner dependence, financial exposure, and business model implications. Treating these aspects jointly enables managers to

anticipate misalignments early, reducing the risk of allocating scarce resources to initiatives unlikely to create sustainable value.

The phase-based framework developed in Chapter 4 (Figure 7) serves as both a reflective device and a roadmap. Its practical value lies in supporting informed judgment before irreversible commitments are made. By explicitly linking technology assimilation and BMI processes, the framework helps managers recognize that even operationally motivated technology projects entail downstream consequences for value creation, delivery, and capture. In this sense, outcomes such as postponement, partial implementation, or discontinuation should not be interpreted as managerial failure, but as rational and informed responses to contextual constraints and evolving information.

For innovation intermediaries, including consultants, technology providers, cluster organizations, and publicly funded project consortia, the thesis highlights the limitations of technology-promotion logics that assume uniform readiness across SMEs. The empirical patterns identified in Chapters 3 and 4 show that SMEs introducing similar technologies may require fundamentally different forms of support depending on their organizational maturity, market access, and strategic intent. Segmenting SMEs based on transformation conditions and trajectories, rather than on industry or technology type alone, enables more targeted and effective intervention strategies. This perspective shifts the role of intermediaries from promoting adoption toward facilitating alignment, experimentation, coordination, and feasibility assessment across transformation phases.

From a policy perspective, the findings challenge diffusion-oriented approaches that prioritize technology acquisition or demonstration without sufficient attention to organizational and BM feasibility. Public initiatives focused primarily on reducing acquisition costs or showcasing technological performance may overlook the main reasons why SMEs struggle to progress. The evidence presented in this thesis shows that organizational readiness, coordination demands, and market alignment are at least as critical as technological characteristics in shaping transformation outcomes. Policy instruments that combine experimentation support with capability development, BM exploration, and partnership facilitation are therefore more likely to generate durable and meaningful effects.

The classification of transformation trajectories developed in Chapter 3 (Figure 5) provides an additional tool for policy learning and evaluation, enabling the grouping of SMEs according to their characteristics and expected trajectories. By demonstrating that partial or low-level transformation outcomes are common and structurally conditioned, the thesis offers a basis for interpreting program outcomes beyond binary success–failure metrics. This perspective enables

policymakers to distinguish between stalled transformations resulting from inadequate program design and those reflecting informed strategic restraint by SMEs operating under uncertainty.

Finally, the phase-based framework introduced in Chapter 4 offers a structured reference for coordinating managerial and policy interventions over time. Its primary contribution is not to accelerate adoption, but to clarify when different forms of support are most relevant. Early phases benefit from support for sensing, alignment, and experimentation, while later phases require greater attention to coordination, partner management, financial assessment, and market access. Recognizing these shifting requirements enables managers, intermediaries, and policymakers to allocate resources and attention more effectively across the transformation process.

Taken together, the empirical and practical implications of this thesis point toward a more reflexive, context-sensitive, and process-aware approach to supporting technological transformation in SMEs. By emphasizing diagnosis, alignment, and informed decision-making, the thesis reframes technological transformation not as a linear adoption challenge but as an organizational process that requires differentiated support at each stage.

5.6. Limitations and future research

This section outlines the limitations of this thesis and suggests directions for future research. While the thesis provides broadly applicable insights into technological transformation for SMEs, the context-dependent nature of this phenomenon (Wu et al., 2022; Teoh et al., 2022; Sabatini et al., 2022) indicates that further adaptations may be needed to obtain more precise insights. This context dependence represents an overarching limitation affecting all three studies, which will be discussed alongside specific limitations and recommendations for future research.

Chapter 2 presents a general framework and associated concepts related to technological transformation in SMEs. However, future research could refine these insights by focusing on specific industry sectors, technology types, or organizational contexts, each presenting unique conditions. Tailoring these general insights to specific contexts could deepen the understanding of technological transformation across diverse settings and enhance the applicability of the findings. The following discussion revisits the research avenues presented in Chapter 2, examining how some of those avenues were addressed, the limitations encountered, and offering suggestions for future research, including those that were not addressed due to research scope and time constraints.

[1] Process of technological transformation

Chapters 3 and 4 examine the technological transformation process in SMEs from distinct perspectives. Chapter 3 provides a qualitative exploration of transformation experiences among agri-food SMEs, utilizing retrospective, self-reported accounts from a diverse sample that highlights varied technologies and objectives. This approach may limit a comprehensive understanding of transformation dynamics. In contrast, Chapter 4 applies a structured framework to guide agri-food SMEs through the transformation process; however, the study's limited timeframe, COVID-19 delays, and consortium support have influenced the process sequence and decision-making. Future research should consider longitudinal studies that track SMEs' entire transformation journeys across various contexts, such as different sectors, technology types, and countries, to enhance understanding of the conditions that shape transformation outcomes (Teoh, 2022; Sabatini et al., 2022).

To better assess the framework's applicability in more typical scenarios, future research should explore its application in contexts in which SMEs navigate the technological transformation process independently, without external support. Additionally, external factors such as COVID-19, multiple attempts to align technologies with pilot agri-food SMEs, and the predefined project timeframe shaped the application of the framework and limited observation to the decision point just before technology commitment. To gain a more comprehensive understanding, future studies should apply this framework using longitudinal approaches that track the entire technological transformation process.

Adapting the model to larger firms could reveal differences and offer deeper insights into how transformation unfolds across various organizational contexts (Teoh, 2022). Additionally, exploring adaptations of the framework for specific technologies — such as digital technologies, which require detailed guidelines for SMEs (OECD, 2021; Sagala & Őri, 2024) — would be particularly valuable. Refining the framework by incorporating concepts specific to these technologies, which this study did not focus on, could enhance its applicability. Moreover, applying the framework to advanced technologies like Industry 4.0, where companies face challenges in creating value and managing costs (Moeuf et al., 2018; Müller et al., 2018), could provide significant insights and further improve its relevance, making it a more robust tool for guiding SMEs through complex technological transformations.

[2] Outcomes of technological transformation

Chapter 3 classifies transformation outcomes in agri-food SMEs, identifies influential conditions, and notes limitations arising from its retrospective, self-assessed approach and sample heterogeneity. The findings present patterns within the sector; however, further research across diverse contexts (e.g., sectors, countries) could yield broader, more transferable insights into transformation outcomes. To enhance outcome analysis, future studies could focus on more homogeneous samples and consistent technologies, providing practical guidance on transformation best practices (Priyono et al., 2020). Additionally, expanding performance metrics to include industry-specific benchmarks or non-monetary outcomes, such as environmental impacts, may increase relevance in line with evolving business sustainability priorities (Kumar et al., 2022).

[3] Technological transformation in different settings and from different perspectives

Chapter 2 provides a comprehensive literature review in a broad context, followed by Chapter 3's qualitative study on EU agri-food SMEs and Chapter 4's process framework, both centered on the perspectives of owner-managers. These chapters indicate that insights into transformation are often context-specific, primarily emphasizing developed countries and SME management viewpoints. Further research is recommended to diversify contexts, particularly in underexplored sectors and developing countries, to enhance understanding of how various combinations of conditions influence technological transformation (Teoh, 2022; de Mattos et al., 2024).

Incorporating broader stakeholder perspectives, including those of employees and supply chain partners, may provide a more holistic understanding of the challenges and opportunities of technological transformation within the SME ecosystem. Additionally, within organizations, the framework could be adapted to integrate perspectives from various internal departments, such as sales, marketing, and product development, fostering cross-departmental collaboration and a more cohesive approach to technological transformation.

[4] Risks and their mitigation in technological transformation in SMEs

Chapter 3 examined a case in which an SME discontinued its use of HPP technology due to market-acceptance issues, despite the technology's superior performance. However, the limited number of such cases within the sample constrains the ability to generalize and identify consistent patterns. Recent research emphasizes the importance of examining failures as crucial opportunities for growth and as foundational steps toward future success (Rhaiem & Amara,

2021). Failure can occur at various stages of the innovation process: (i) idea failure, where the project is terminated before resources are committed; (ii) technological failure, during the development phase; and (iii) commercial failure, after-market introduction (Shepherd et al., 2009; D'Este et al., 2016; Rhaiem & Amara, 2021).

Future research should include a broader range of unsuccessful cases to better understand the conditions contributing to failure. Additionally, developing tools to identify and mitigate these risks would be invaluable. By focusing on both successful and unsuccessful cases, future studies can help create more robust strategies that better prepare SMEs for the challenges of technological transformation.

[5] BMI as a precursor of technology assimilation

Future studies could investigate how BMI can actively support SMEs in introducing new technologies, whether in-house or outsourced. This includes exploring potential modifications to technology providers' BMs or developing collaborative BMs promoted by technology providers, governments, or industry associations. These entities can play a crucial role in enhancing value mechanisms to better meet the specific needs of SMEs, especially regarding new and advanced technologies that are often less accessible due to their complexity, high skill requirements, or challenges in realizing their value (Akpan et al., 2022). Additionally, SMEs that are early adopters of advanced technologies have significant potential to offer services to others facing similar challenges. This opportunity, highlighted by Müller et al. (2018) and by our findings in Chapter 3, shows how pioneering SMEs often transition into service providers, thereby further capitalizing on their early adoption. Future studies could explore this potential more deeply by examining how these SMEs leverage their expertise to create new BMs and foster broader technology introduction.

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Appendices

Appendix A: Organization characteristics

N	Technology	Age	Size	Country
1	Technology tailored to modify the flavour of sports nutrition products	3 years	Micro	NL
2	Cold chamber for preserving products to extend the shelf life of the fruits	40-50 years	Medium	PT
3	Innovative model for cultivating mushrooms from organic materials, with the goal of producing vegetarian meat from the protein extracted from fungi	9 years	Micro	NL
4	Innovative process for extracting distinctive compounds from natural microorganisms like baker's yeast, brewer's yeast, and micro-algae	less than 1 year	Micro	NL
5	Web platform that enables an innovative model for crowdfunding high-quality meat to sustainable oriented consumers	6 years	Small	NL
6	Closed-loop hydroponic system that reuses water from aquaculture while repurposing the waste generated from fish processing to produce pet food	3 years	Micro	AT
7	Specialized oven to stabilize spirulina algae	5 years	Micro	NL
8	New production line (new drink)	2 years	Micro	NL
9	HPP technology for cold-pressed juices	6 years	Micro	IT
10	Novel method for manufacturing groundbreaking products, such as a healthy dairy-based shot containing extra virgin olive oil	less than 1 year	Micro	NL
11	Technology for repurposing pruning waste and machinery to create wood chips through recycling	3 years	Micro	IT
12	Online platform for promoting handicraft products and acquiring new customers	2 years	Small	ESP
13	Energy efficiency technology and controlled atmosphere	8 years	Small	GR
14	Breeding technology for lamb production and pressure plant	12 years	Small	HU
15	CRM facilitates the growth of food companies by establishing pertinent networks	4 years	Micro	Romania
16	New machinery for improving flow pasteurization	7 years	Micro	Serbia
17	Maurer flow pasteurizer	7 years	Micro	Serbia
18	Two-phases olive mill	20 years	Micro	Greece
19	Innovative food product technology for incorporating oregano into cheese	92 years	Small	Greece
20	Innovative olive mill	50 years	Small	IT
21	Platform for connecting farmers and consumers	3 years	Micro	UK
22	New tractors	5 years	Micro	Romania
23	New olive mill	100 years	Small	PT
24	Line of cocktails without alcohol	2 years	Micro	NL

25	Technology for manufacturing dried tomatoes with reduced sodium content	26 years	Micro	IT
26	Scalable process for manufacturing molasses with figs	13 years	Micro	IT
27	Technology to enhance field operations	7 years	Medium	IT
28	E-commerce platform dedicated to curating and offering an exquisite selection of EVOO	3 years	Micro	IT
29	Cold chamber for preserving products to extend the shelf life of grapes	40 years	Micro	IT
30	Novel tractor sensor aimed at enhancing operational efficiency in the field	More than 10 years	Micro	IT
31	Novel crop varieties and innovative field protection systems	48 years	Micro	IT
32	Innovative systems for indoor microgreens cultivation	2 years	Micro	IT
33	Innovative systems for indoor microgreens cultivation	4 years	Micro	IT
34	Innovative systems for outdoor microgreens cultivation	4 years	Micro	IT
35	Energy efficiency technology (solar panel in the winery)	30 years	Medium	IT
36	Innovative plant-based packing	20 years	Micro	IT
37	HPP for cold-pressed pomegranate juice	6 years	Small	IT
38	Olive harvesting machine	30 years	Micro	IT
39	Olive harvesting machine	50 years	Micro	IT

Summary

The rapidly evolving global business environment, characterized by new regulations, technological advancements, heightened competition, and significant disruptions like the COVID-19 pandemic and the Fourth Industrial Revolution, presents numerous challenges and opportunities for organizations. These dynamics compel small and medium-sized enterprises (SMEs) to continuously innovate their production methods and business models (BMs) with the introduction of technologies to remain competitive and survive. Despite the recognized importance of technological transformation, there remains a gap in understanding how SMEs can effectively manage this process.

Against this backdrop, this thesis sets out to address the overarching research question*: How can an integrative framework for the technological transformation process be developed to support and guide the organizational transformation that SMEs undergo when introducing new technologies?* This research is structured around the following three specific research questions (RQs):

RQ1: What is the state of the art in the literature on technological transformation in SMEs?

RQ2: How do EU agri-food SMEs assimilate new technologies, innovate their business models, perceive performance, and what conditions influence their transformation levels and performance perceptions?

RQ3: How can a conceptual framework be structured to include relevant concepts, phases, and tools to represent the technological transformation process and assist SMEs in understanding and undergoing it, and to what extent does its application validate its logical coherence, enhance understanding of the process, and uncover previously unidentified insights?

In Chapter 2, the thesis examines the current state of the literature on technological transformation in SMEs, addressing RQ1. Through a systematic review of 165 peer-reviewed papers, it identifies key themes and patterns in this fragmented and multidisciplinary field. The chapter outlines the core elements of technological transformation, including drivers, barriers, enablers, controls, processes, and outcomes, and integrates these into a visual and sequential framework. The findings highlight and offer insights on the interconnectedness of technology

assimilation and business model innovation (BMI). The chapter concludes by proposing five research avenues for further exploration in subsequent chapters.

Chapter 3 explores the technological transformation of EU agri-food SMEs and addresses RQ2 by analyzing 39 case studies, focusing on their outcomes and the conditions shaping them. It identifies distinct patterns of technological transformation trajectories across 10 SME groups, alongside patterns in technology assimilation, BMI, and performance. The findings show how SMEs modify their business models (including the affected value elements) and assimilate technologies (including the strategies employed and the proficiency achieved) while highlighting the technological, organizational, and environmental conditions that shape both the transformation process and its outcomes. The chapter underscores the importance of aligning technology assimilation, BMI, and the broader business context to enhance performance.

Building on insights from Chapters 2 and 3, Chapter 4 proposes a conceptual framework designed to guide SMEs through the technological transformation process, addressing RQ3. This framework, developed through an exploratory conceptual development approach combining systematic and iterative literature analysis with qualitative empirical validation. The framework is applied to three pilot agri-food SME cases, demonstrating its logical coherence and practical applicability. The chapter also reveals insights into the conditions influencing technological transformation, offering a more detailed and structured approach to managing this complex process.

Chapter 5 synthesizes the findings from the previous chapters, providing a comprehensive discussion of the implications for both theory and practice. The chapter emphasizes the critical role of context in shaping the technological transformation process and highlights the importance of an integrative approach that considers the interplay between technology assimilation, BMI, and the broader organizational environment. The thesis concludes with recommendations for future research.

Acknowledgement

As Heraclitus once observed, no person ever steps into the same river twice. This doctoral journey has profoundly transformed me, and I will not emerge from it the same person I was when I began. I therefore wish to begin by acknowledging those who shaped not only this work, but also the person I have become along the way.

First and foremost, my deepest gratitude goes to my father, João Roberto Loureiro de Mattos, who sadly passed away during my PhD. You were far more than a father; you were my mentor in life. You instilled in me the value of education, encouraged me to question certainties, and taught me to seek evidence before accepting conclusions. As a PhD holder, engineer, and outstanding manager, you inspired me to follow this path and offered guidance precisely when I needed it most.

You also taught me the meaning of dignity, courage, and integrity, and you always stood up for what is right and persevered until the very end. Actions speak louder than words, and I follow your example by standing firm for the ultimate consequences in the name of what is right. You taught me how to position myself as a professional and navigate institutional dynamics. You showed the value of working relentlessly to ensure that nothing essential was ever lacking: safety, health, and above all, education. You once told me that a person should have children, plant a tree, and write a book. In saying this, you were being modest; you achieved all of that and much more. Your legacy continues to guide me, and I dedicate this work to your memory. I am also deeply grateful for the network you built, which supported me during the most difficult moments of my PhD.

A special thank you goes to my mother, Marta Mattos, whose strength, faith, humour, and clarity have sustained me throughout this journey. You come from a generation of women who refused to accept the places assigned to them, and you taught me never to lower my head, never to seek approval at the cost of my convictions, and always to recognise my own strength. You taught me resilience, mental fortitude, and trust in my own judgment, even when voices around me spoke otherwise. I am grateful to belong to a lineage of women who break boundaries and expectations.

Still in this line, I thank you all, WUR Women, for your support during challenging moments, which made a lasting difference.

I would also like to express my deep gratitude to my siblings, Júlia Mattos and Gustavo Mattos. After an extended period marked by intense pressure, you reminded me of what home truly means: belonging, care, and continuity. At a time when accumulated challenges weighed

heavily, particularly after the loss of our father, you helped me remember who I am and where I come from. Your presence restored perspective, strengthened me when I was exhausted, and reminded me of the power of unconditional love and of lifting one another in moments of vulnerability.

My heartfelt thanks also go to Richard Chaplin and Bauni, who were my constant companions throughout this period, sharing the joys of the good days and carrying me through the difficult ones. Richard, you truly saw me. During one of the most demanding periods of my life, you never let go of my hand. In moments when I could no longer recognise anything good in myself, you continued to see what I could not and reminded me of who I had been before the weight of this process took hold. You welcomed every change I went through, as we have both evolved profoundly over the years, and you embraced the person I became with openness and generosity. More than this, you helped me grow into a stronger version of myself, offering steadiness, perspective, and unconditional support. For all of this, I will always be grateful.

I extend my sincere appreciation to the professionals and wider network who supported me during the most trying phases of this process, particularly Amábile Rodrigues and Atilas Lopes. Your empathy, support, care, and timely reminders of my own values will remain with me long after this journey has ended.

I want to express my deepest gratitude to Geoffrey Hagelaar for guiding me throughout this project with steadiness, humility, generosity, and trust. Geoffrey, you exemplify research excellence at Wageningen University, and you taught me to value the process itself, helping me navigate difficult moments with composure and perspective. Your ability to remain intellectually curious, to reposition yourself, and to continue learning even at the most advanced stage of a career has been an inspiring example. Working with you has been a privilege. I am also grateful to Giustina Pellegrini and Wilfred Dolfsma for their supervision and support.

Finally, I wish to thank my family, friends, and the many colleagues I had the pleasure of meeting, both within the BMO group and across the courses I attended. As people naturally come and go during a PhD, I have chosen not to single out individuals in order to avoid omissions; nevertheless, every interaction, however brief, left its mark on this experience. A special word of thanks goes to those with whom I shared an office: you made long days lighter, small victories sweeter, and created memories I will always cherish. I also thank the professors who contributed to my training and with whom I enjoyed many thoughtful conversations.

Approved training and supervision plan

Camila Silva de Mattos
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
A1 Managing a research project			
WASS Introduction Course	WASS	2019	1
Writing the research proposal	WUR	2020	6
A2 Integrating research in the corresponding discipline			
Research Methodology: From topic to proposal	WASS	2019	4
Advanced Qualitative Research Design and Data Collection - GEO-56806	WUR	2020	6
Multivariate Data Analysis– YRM-50806	WUR	2022	6
B) General research related competences			
B1 Placing research in a broader scientific context			
Cooperatives and Producer Organisations - BMO57806	WUR	2022	6
B2 Placing research in a societal context			
Writing a popular magazine article or newspaper article	WUR	2022	1
C) Career related competences/personal development			
C1 Employing transferable skills in different domains/careers			
Research data Management	WUR	2021	0.45
Start to teach	WUR	2021	1
Total			**31.45**

*One credit according to ECTS is on average equivalent to 28 hours of study load

The research described in this thesis was financially supported by the European Union's Horizon 2020 research and innovation program under Grant Agreement No. 817936. Support from Wageningen University for printing this thesis is gratefully acknowledged.

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