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Industry 4.0 and sustainable business models: An intercontinental sample

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Abstract

In the rapidly evolving contemporary business landscape, the Industry 4.0 revolution has emerged as an immense and transformative force, fundamentally reshaping industries and presenting significant challenges to prevailing business models. As technology components continued to evolve in response to this revolution, it became increasingly evident that understanding the multifaceted implications of these changes for organizational sustainability is of paramount importance. The overarching goal of this research was to elucidate the intricate interplay between Industry 4.0 technologies and organizational sustainability. To achieve this objective, we conducted a comprehensive exploration of real-world instances where companies boldly embraced Industry 4.0 technologies, subjecting their specific practices and processes to thorough examination. This methodological approach yielded a wealth of invaluable insights into the practical implications of Industry 4.0 on organizational sustainability, effectively bridging the gap between theory and practice. This research underscores the urgent need to provide businesses and decision-makers with insights of paramount significance. The findings of the study aim to serve as a guiding compass for organizations, offering clarity on potential benefits and challenges associated with Industry 4.0 adoption. Notably, within the scope study, the utilization of semi-structured interview technique added a unique dimension, enabling in-depth insights. Interviews were conducted with individuals from diverse nations across different continents, thoughtfully selected based on predefined criteria, setting this research apart in terms of both the sample's size and the remarkable diversity within the participant profile. This diversity enriched the research findings by encompassing various perspectives and experiences, significantly enhancing the depth and breadth of the study's insights.

KEYWORDS
business transformation, Industry 4.0, organizational sustainability, practical implications, technology evolution

Abbreviations: AI, Artificial Intelligence; AR, Augmented Reality; Covid-19, Corona Virus Disease of 2019; GDP, Gross Domestic Product; HRM, Human Resources Management; Industry 4.0, Fourth Industrial Revolution; IoT, Internet of Things; MVA, Market Value Added; R&D, Research and Development; RBV, Resource-Based View; SMEs, Small and Medium Enterprises; TAI, Technology Achievement Index; WEF, World Economic Forum; VR, Virtual Reality; 5G, Fifth-Generation.

1 | INTRODUCTION

Since the dawn of humanity, the pursuit of development and progress has been an inseparable facet of our existence (Schwab, 2016, p. 15);

prior to the 18th century, agrarian and animal husbandry practices prevailed as the primary sources of sustenance (Bayarçelik, 2020, p. 59; Koc & Teker, 2019, pp. 304–305). Communities during this epoch produced in alignment with their basic needs and societal demands, profoundly cognizant of the value of human labor. However, the second half of the 18th century emerged as an important era in human history. The advent of steam engines ushered in industrial development, gradually substituting muscle power with mechanical innovation and laying the foundational sparks of today's sophisticated production technologies (Küçükkalay, 1997, p. 52; Schwab, 2016, p. 15). Throughout history, industrial revolutions have consistently triggered transformative waves that resonate deeply within the societies they impact, reshaping the trajectories of individuals and groups. Industry 4.0 stands as the herald of another transformation on the horizon. At its core, this concept is predicated on the convergence of widespread internet connectivity, adaptable production systems, and the infusion of technology into manufacturing processes (Hisarcıklıoğlu, 2016, p. 6; Machado et al., 2020, p. 1463; Upadhyay et al., 2023). It envisions a world where every animate and inanimate entity is tethered to the internet, fostering inter-machine communication and heralding the era of intelligent production (Eldem, 2017, p. 10).

Contemporary global industries find themselves amidst a profound transformation, driven by technological advancements that are recalibrating the contours of manufacturing, operations, and business conduct. This transformation, often denominated as "Industry 4.0," transcends mere innovation; it marks a fundamental revolution characterized by unparalleled connectivity, automation, and data-driven decision-making (Lu, 2017, p. 6). Industry 4.0 seamlessly integrates cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), and data analytics, altering the industrial landscape (Schwab, 2016; Sestino et al., 2020, p. 2). Simultaneously, the call for sustainable development and environmentally responsible business practices has surged with unprecedented urgency. Climate change, resource scarcity, and a growing demand for ethical and responsible corporate behavior have propelled sustainability to the forefront of corporate concerns (Shin & Jin Park, 2017, p. 80). The interface between the rapid advancements of Industry 4.0 and the imperatives of sustainability underscores a critical challenge and opportunity of our era (Jamwal et al., 2021, pp. 2–3).

This paper embarks on a comprehensive exploration of the juncture between Industry 4.0 and sustainable development, with a distinct focus on the means by which Industry 4.0 technologies and strategies can bolster sustainable business models. It scrutinizes Industry 4.0's potential to enhance resource efficiency, minimize environmental impact, and elevate the social and economic dimensions of sustainability. In the ensuing pages, we will traverse the key elements of Industry 4.0, scrutinizing the foundational technologies and their applications across diverse industries. Simultaneously, we will examine the ever-evolving landscape of sustainable business models and practices. The paper also aspires to provide valuable insights into how businesses can harness Industry 4.0 not only to attain operational excellence but also to align their operations with sustainable principles.

In the pursuit of these themes, we aspire to contribute to the burgeoning body of knowledge pertaining to the intersection of technological innovation and sustainable development. Our primary goal is to provide some advice and inspiration to entrepreneurs, policymakers, and researchers who tend to create a more prosperous and sustainable future. Herewith, this paper builds upon a comprehensive theoretical research foundation developed through extensive literature review and analysis. The theoretical underpinnings of Industry 4.0 and sustainable business models have been rigorously examined, serving as the bedrock upon which this empirical study is founded. These theoretical frameworks not only inform the research but also set the stage for the forthcoming pages of this study.

In the chapters that follow, we will navigate through empirical findings that corroborate, extend, or challenge the established theoretical constructs. We hope to bridge the theoretical-practical divide and shed light on the relevance of these theories in real-world organizational situations. The synthesis of theoretical insights and empirical observations will offer a holistic perspective, enabling a deeper understanding of the complex interplay between Industry 4.0 and sustainability. This integration will serve as the backbone of our investigation and contribute to the expanding body of knowledge in this field. In pursuit of a comprehensive understanding of the nexus between Industry 4.0 and sustainable business models, this research embarks on a novel path by engaging in interviews with global firms. This empirical investigation unfolds with a diverse and sizable sample, a distinctive feature that adds a layer of uniqueness to our research endeavor. In this regard, it is worth noting that there is a remarkable scarcity of earlier work utilizing a sample of this size within the field of academic literature.

Our choice of conducting interviews with middle and senior managers from global organizations, guided by specific criteria, bolsters the richness and depth of our study. This approach allows us to glean insights from a broad spectrum of corporate perspectives, facilitating a more comprehensive understanding of the practical intricacies of implementing Industry 4.0 technologies and strategies within the context of sustainability. The ample sample size enhances the robustness of our findings and presents a valuable contribution to the existing body of knowledge in this domain. As we progress through this research, the insights drawn from these interviews will be juxtaposed with established theories, forging a nuanced narrative that underscores the practical implications of our theoretical constructs. This methodological approach is integral to our mission of providing practical insights that transcend the boundaries of theoretical discourse, shedding light on the intricate challenges and opportunities that global organizations encounter as they navigate the transformative landscape of Industry 4.0 with sustainability at the forefront.

Comprising six chapters, this research spans a comprehensive journey. The initial chapter imparts foundational knowledge to orient readers. The second chapter delves into the theoretical constructs of "Industry 4.0" and "Business Model." Subsequently, the third chapter unveils the intricacies of the research methodology, while the fourth chapter synthesizes the research findings. The fifth chapter fuses these findings with existing literature, delivering an extensive analysis. Lastly, the sixth and final chapter contemplates the research's discoveries and its intrinsic constraints and furnishes valuable recommendations for future academic pursuits. Thence, this paper encapsulates the evolving interplay between technology, business, and

sustainability, bridging the historical and contemporary. It captures the enduring human quest for progress, underscored by the imperatives of holistic development within an increasingly interconnected world.

2 | THEORETICAL FRAMEWORK

Since innovative technologies have the capacity to alter the balance between organizations and reshape the conditions of competition, technological developments create new opportunities for organizations in every era they operate (Christensen et al., 2015). The inability to comprehend the effects of emerging technologies on business models can be disastrous for organizations (Tripsas & Gavetti, 2000). For example, companies like Kodak, Nokia, and Blackberry, which were unable to discern the technological change process of digital cameras and smart phones, were nearly driven out of the market because they were unable to adjust their business models to the changing technological environment. As a result, the compatibility of business strategies with technological change and digital transition is crucial (Graham et al., 2023, pp. 1–2; Holotiuk et al., 2017, p. 912).

In the context of this research, the theoretical framework seeks to illuminate the transformative nature of the Industry 4.0 revolution and its profound influence on contemporary business models, with a primary focus on the lens of organizational sustainability. The unique contribution of this theoretical framework lies in its comprehensive analysis of the constituent components of Industry 4.0, while also highlighting innovative perspectives in understanding the problem of how these technologies impact business sustainability. The core premise of this framework begins with a detailed exposition of the fundamental components of Industry 4.0. The IoT, AI, big data analytics, and automation are among these components. There are several more technological components outside these highlighted ones; however, they are brought out within the scope of this research. So, these components are explored in-depth by the light of literature, elucidating their individual and collective implications for contemporary business operations and strategies. By emphasizing these basic components, the framework contributes by providing a holistic view of the Industry 4.0 landscape, which serves to inform and enrich the existing literature on technological advancements within business environments.

Integral to the framework is a robust definition and exploration of organizational sustainability. Recognizing the diverse nature of sustainability in the present corporate world, this includes economic, environmental, and social components. Here, the framework contributes by establishing a comprehensive backdrop against which the impacts of Industry 4.0 technologies on sustainability can be assessed, offering a nuanced lens that aligns with the holistic nature of the research problem. Existing theoretical perspectives relevant to the study are addressed within the framework. These may include theories of organizational change. However, this framework contributes innovation by synthesizing these perspectives into a comprehensive understanding of how Industry 4.0 technologies challenge and enhance these theoretical models. This approach broadens the scope of current literature, offering a more dynamic perspective on the interplay between technology and organizational sustainability. The important theories previously put forward in the literature on the subject are as follows:

- Innovation Diffusion Theory: This theory, popularized by Rogers (1962), explores the process by which innovations, in this case, Industry 4.0 technologies, are adopted and diffused within organizations to investigate how the adoption of these technologies impacts organizational sustainability, drawing upon this theoretical framework.
- Resource-Based View (RBV): The RBV, as articulated by Barney (1991), focuses on a firm's internal resources and capabilities as sources of competitive advantage to assess how Industry 4.0 technologies contribute to a firm's resource base and sustainable competitive advantage.
- Dynamic Capabilities Theory: Teece (2007) developed the dynamic capabilities theory, which emphasizes an organization's ability to adapt and reconfigure its resources to respond to changing environments. In the context of Industry 4.0, it explores how firms build dynamic capabilities to leverage new technologies for sustainability.
- Institutional Theory: This theory, as developed by DiMaggio and Powell (1983), explores how organizations conform to and are influenced by societal and institutional norms to understand how Industry 4.0 adoption is shaped by institutional pressures and how it, in turn, influences sustainability practices within organizations.
- Systems Theory: Systems theory, which has various proponents (Applewhite et al., 1975; Bertalanffy, 1968; Laszlo, 2021; Meadows et al., 1972; Wiener, 2019), views organizations as complex systems with interrelated components to analyze how Industry 4.0 technologies influence the entire organizational system, including its sustainability efforts.
- Sustainability Theories: Sustainability Theories, depending on the focus (economic, environmental, social), can draw upon specific sustainability theories, such as the Triple Bottom Line (Elkington & Rowlands, 1999) or the Natural Capital Theory (Costanza & Daly, 1992; Farber, 1999; Schumacher, 1973), to guide analysis of how Industry 4.0 affects different dimensions of sustainability.

The framework based on this theories serves as the foundation for the formulation of research, directly related to the anticipated relationships between Industry 4.0 technologies and organizational sustainability. This theoretical framework is validated through a qualitative analysis, involving a combination of semi-structured interviews and literature review. By grounding the theoretical framework, the research contributes by offering a systematic and data-driven approach to test the theoretical concepts, thereby fostering the application of innovative research methodologies and also leads to a comprehensive discussion of the empirical findings, providing insights into how Industry 4.0 technologies impact different dimensions of organizational sustainability. In its conclusion, the framework underscores

the practical implications of the research for businesses and policymakers, thereby contributing innovative solutions and insights to address the challenges and opportunities posed by the Industry 4.0 revolution. And this theoretical framework not only provides a structured approach to our research but also highlights the novel contributions and innovative aspects that differentiate our study within the academic landscape. It offers a comprehensive perspective on the complex interplay between Industry 4.0 technologies and organizational sustainability while underscoring their multifaceted impact.

But here, first of all, it is necessary to understand well what a "business model" is. Many researchers have sought to define the business model, which has become one of the most often encountered concepts in today's business environment. One of these meanings defines the idea as "a tool that offers a simplified representation of a business's pertinent operations" (Panic & Vucurovic, 2021, p. 327). A business model, according to another description, is "a reflection of the company's plan" (Casadesus-Masanell & Ricart, 2010, p. 195). In a nutshell, the authors defined the term as "the story that describes how a business works" or "the way businesses do business" (Holotiuk et al., 2017, pp. 913–914). Although there is no common meaning of the business model idea in the literature, definitions put forward about the concepts usually concentrate on two fundamental elements: Strategy and Value-Creating Activities (Geissdoerfer et al., 2018).

Indeed, it is evident that a dichotomy exists within scholarly discourse, with certain researchers asserting the inseparability of the business model from strategic considerations, while conversely, a contrary perspective is embraced by a cohort of scholars. Advocates of the latter viewpoint posit that the business model should be regarded as an independent conceptual construct, distinct from the overarching strategy (Massa et al., 2017). As per researchers who share this viewpoint, strategy, rather than a business plan, is the primary factor underlying the competitive nature. Consequently, despite their fundamental differences, the two notions are inextricably linked (Wirtz et al., 2016). In addition, strategy can be seen as a future position or situation that an enterprise aims to achieve, while a business model defines an organization's current position (DaSilva & Trkman, 2014). There are also views that argue that a business model should be seen as the link between strategy and its operational implementation (Wirtz et al., 2016). As can be seen, although there are different explanations and definitions in the literature, a business model in general is a way of expressing how the organization works, and businesses determine their own implementation paths with their own strategies (Massa et al., 2017; Panic & Vucurovic, 2021, p. 327).

The concept of business model is a relatively new concept in management studies (Al-Debei & Avison, 2010). Although the concept emerged in the 1950s, it did not capture the attention of scholars until the end of the twentieth century (Osterwalder et al., 2005). The business model is concerned with how an organization creates, communicates, and delivers value (Osterwalder & Pigneur, 2010), and the concept of "value" has been central to most of the explanations made by researchers since the first studies published on the subject (Chesbrough & Rosenbloom, 2002; Wirtz et al., 2016). Technological innovations alone do not ensure an organization's success (Zott et al., 2011); therefore, a business model acts as a mediator between economic value creation (Chesbrough & Rosenbloom, 2002) and organizational performance (Baden-Fuller & Haefliger, 2013). In this manner, it provides a competitive advantage to organizations (Johnson et al., 2008). The capacity of a new technology to act as a value creation instrument and adjust to the company is critical to its economic success (Teece, 2010). For this reason, it has become imperative for today's businesses to read the opportunities and threats arising from technological changes (Holotiuk et al., 2017, pp. 913–914).

Business model innovation assumes paramount significance, as even well-established and prosperous business models may warrant rejuvenation or, in certain instances, complete overhaul. Effecting such changes in the business model necessitates an initial impetus, which can be instigated by a spectrum of factors, both internal and external. Of these factors, particularly salient in the contemporary industrial landscape, are the advent of emerging technologies. The development of new technologies can wield a transformative impact on organizational processes related to value creation and cost structures, thus emerging as a pivotal determinant in the revitalization of existing business models (Teece, 2010). When organizations fail to realign their business models with the demands of new technologies, they risk operating below their inherent potential, necessitating the formulation of a new business model to harness the full scope of their capabilities (Chesbrough, 2010). This underscores the indispensable link between technology and the evolution of business models (Panic & Vucurovic, 2021, p. 328).

Amidst diverse interpretations and perspectives regarding the conceptualization of a "business model," its pivotal role remains unquestionable in facilitating the execution of organizational strategies, contributing significantly to market success. Market performance is contingent upon a multitude of factors, rendering it susceptible to fluctuations attributed to environmental influences (Panic & Vucurovic, 2021, p. 332). Such fluctuations typically necessitate the adaptation of existing business models or the innovation of entirely new models. Consequently, organizational strategies exhibit dynamic characteristics. The initial business strategy formulated during a company's inception is seldom equipped to ensure sustained success, thus warranting a perpetual focus on innovation. The process of revising the business model and aligning it with evolving circumstances emerges as an imperative for long-term organizational viability. These transformative adjustments can be prompted by both internal and external factors, underscoring their multidimensional nature (İnan et al., 2022, pp. 6–7; Lopes et al., 2017, p. 476). The advent of novel technology, particularly when it presents organizationally efficient and sustainable solutions, precipitates a comprehensive reevaluation and scrutiny of existing business models. Competition, renowned as a pivotal determinant for the sustainability of organizations, exhibits a sensitivity to an array of internal and external environmental variables. In this regard, the realization of a change in the business model bears a direct influence on the competitive dynamics, a facet of paramount significance for enterprises (Horak et al., 2018, p. 528; Johnson et al., 2008).

Looking back over the years, we can see that the process that began with the first industrial transformation has had an influence all over the world, notably afterwards the Industrial Revolution, and has directly impacted man's interaction with nature and other people. This

process of change and interaction has also been reflected in industrial activities, and certain factors have led to numerous (r)evolutions in the industrial field, which differ within themselves until today. Today, a new concept has been introduced under the name of "Industry 4.0" and many new technological components based on this concept have started to take place in organizational processes. In this new era of industrial production based on technological developments and digital transformation, it is planned that all units directly or indirectly related to production activities during organizational production activities will work together (Pisching et al., 2015; Prause, 2015; Schuh et al., 2014). Industry 4.0 heralds that our world is on the way to change again. The concept is based on the merging of more prevalent internet use with flexible production systems and the incorporation of technology into production processes (Hisarcıklıoğlu, 2016, p. 6; Schwab, 2016, pp. 18–20). Every object, whether living or inert, will be linked to the internet and interact with one another, and smart production will come to life through computer communication. After the concept was presented, discussions and research into the economic and societal changes that will occur as a result of these developments began (Almada-Lobo, 2016, p. 16; Eldem, 2017, p. 10).

Behind the changes that the concept of Industry 4.0 has gone through since its beginning is the shaping of the concept by the impact of more than one technological feature. Many concepts, such as the IoT, cyber-physical systems, big data, and cloud computing, have an impact on the new industrial transformation, and these concepts are completing their transformation. The systems created with the help of digitalization and technological advancement, as well as these ideas, have an effect on all organizational functions, from manufacturing to marketing (Topsakal et al., 2018, p. 3). Although this situation seems to have emerged on the basis of production, as with other Industrial 4.0 industrial revolutions, it is believed that its potential impacts will not be confined to this area alone. This scenario can be indicated by employment, unemployment, workforce, development, business climate, enterprise, education, and a variety of other socioeconomic problems (Soylu, 2018, p. 44). After this revolution has completed its transformation, current production, consumption, and distribution methods are anticipated to change, as will business models (Berg et al., 2018, p. 5). And some key components of Industry 4.0 are gaining importance due to the impact it is expected to have on business models and sustainability.

Rapid technological breakthroughs, particularly in the realms of Virtual Reality (VR) and Augmented Reality (AR), have significant implications for improving corporate sustainability. VR and AR technologies are not only revolutionizing workforce training by offering immersive and interactive programs that reduce time and costs associated with conventional training methods, but they are also aligning with human resource sustainability objectives. By bolstering workforce skills and productivity while minimizing the environmental impact associated with on-site training sessions, VR and AR contribute to the overall sustainability of businesses (Makransky et al., 2017, p. 276).

Furthermore, IoT sensor deployment is critical in driving sustainability initiatives. These sensors give real-time data on resource consumption, including energy and water consumption, allowing enterprises to maximize resource utilization while reducing waste. Additionally, IoT sensors facilitate predictive maintenance practices, extending the lifespan of assets and reducing the environmental footprint of manufacturing processes by minimizing downtime (Davenport, 2018, pp. 73–75; Margara et al., 2019). And also the integration of data analytics into Industry 4.0 further strengthens sustainability endeavors. By combining data analytics with IoT sensors, organizations can streamline their supply chain operations, reducing transportation costs and greenhouse gas emissions (Sharma et al., 2022, p. 1785). Data analytics also enables organizations to adjust their products and services to customer preferences, reducing waste, considering green technology innovation as important, and increasing consumer satisfaction while supporting economic, environmental, and social sustainability goals (Sahoo et al., 2023, p. 566).

In addition, the adoption of smart manufacturing and 3D printing technologies plays a vital role in sustainability efforts. These technologies substantially reduce material waste and energy consumption through precise and on-demand production, while simultaneously enabling mass customization. By eliminating the need for mass production and excess inventory, these technological innovations align with economic and environmental sustainability goals, contributing to the overall sustainability of organizations (Ford & Despeisse, 2016, p. 1575; Tang et al., 2016, p. 101). Thus, the use of automation and robots not only improves workplace safety and employee well-being by performing repetitive and physically demanding tasks, but it also helps with energy optimization, making operations more energy-efficient and lowering carbon emissions. These technological advancements align with sustainability goals, promoting both the well-being of the workforce and the environmental responsibility of the organization (Kaasinen et al., 2020; Wang et al., 2017, pp. 373–374).

Besides, blockchain technology is enhancing supply chain transparency, enabling consumers to trace product origins, which fosters trust and ethical consumption. This innovation positively contributes to social and environmental sustainability by promoting responsible sourcing and production (Conoscenti et al., 2016, pp. 1–2; Ekşi, 2022). In an increasingly digital landscape, robust cybersecurity measures are indispensable to protect sensitive data. Effective cybersecurity practices safeguard against financial losses and reputation damage, factors that are essential for overall business sustainability (Roman et al., 2013, p. 2270). Drones and autonomous vehicles are optimizing logistics by reducing fuel consumption and transportation costs through route optimization. This enhancement positively impacts both economic and environmental sustainability, by reducing the carbon footprint and resource utilization (Kovacic et al., 2022).

Eventually, with its improved data transmission capabilities, 5G technology enables real-time monitoring and decision-making, boosting operational efficiency and resource conservation. This technology plays a significant role in addressing economic and environmental dimensions of sustainability (Andrews et al., 2014). The comprehensive integration of these advanced technologies into business operations underscores their pivotal role in enhancing sustainability across economic, environmental, and social dimensions, shaping the future of sustainable business models. Apart from these, there are many other components of Industry 4.0, but in this study, the technological innovations that stand out on the subject are emphasized.

In a swiftly evolving global landscape characterized by rapid technological advancements which we mentioned here and also the others, the viability of businesses is contingent upon their ability to adeptly navigate and adapt to these inexorable transformations. At the core of this success lies the business model employed by an enterprise. The extent to which managers closely monitor technological developments and seamlessly incorporate them into their business operations directly correlates with the longevity of their enterprises. Business models, as integral components of the production process and organizational strategies, have assumed an increasingly pivotal role in recent years. Given the escalating competitive landscape of today's organizations, the emergence of novel technological innovations within operational processes has necessitated a reevaluation of established concepts and sparked new dialectical discussions.

Technological advancements within the current industrial landscape have a profound impact on the competitive environment. Organizations that fail to adapt to these technological advances can find themselves behind their rivals, resulting in severe operational disruptions and, in extreme circumstances, market loss. Concurrent with the advent of the Industry 4.0 revolution, the technological advancements taking center stage today exert a transformative influence on the business models of organizations. As technological innovations increasingly integrate into the fabric of organizational production processes, business models have begun to undergo significant reshaping. The adaptability of an organization's business model plays a pivotal role in the context of competitive dynamics and should be regularly reassessed in alignment with the prevailing industrial landscape. Consequently, to thrive in an increasingly competitive milieu and sustain their operations, organizations must realign their business models to meet the demands of the era.

In the preceding theoretical discourse, we have examined the decisive role of Industry 4.0 and technological advancements in shaping contemporary business landscapes and the imperative for organizations to adapt their business models. Now, as we pivot toward the methodology section of this research, our focus shifts to the practical aspects of our study. In this section, we will elucidate the methodologies and techniques employed in our research design. These methodological choices are fundamental to understanding how we gathered and analyzed data to investigate the intricate interplay between Industry 4.0 technologies and organizational sustainability. Our methodological approach was carefully selected to ensure the robustness and validity of our findings, ultimately providing a comprehensive understanding of the impact of Industry 4.0 on organizational practices and sustainability. In the pages that follow, we will outline the specific research methods, data collection strategies, and analytical techniques employed to address the research objectives, shedding light on our empirical approach.

3 | METHODOLOGY

In this section, we delve into the methodological framework that underpins our research. Methodology is the bedrock upon which the empirical aspects of this study rest. It serves as the structured approach guiding our investigation into the intricate dynamics of Industry 4.0 and its influence on organizational sustainability. The methods employed herein have been thoughtfully chosen to ensure the credibility, reliability, and rigor of our findings. This section outlines our research design, data collection techniques, and analytical tools, offering insight into how we have meticulously navigated the terrain of our study to uncover the underlying relationships between technology and sustainability.

3.1 | Purpose of the research

In qualitative research, the researcher tends to construct a theory with an inductive approach instead of testing hypotheses with a deductive approach. Building theory with an inductive approach is one of the most distinctive features of qualitative research (Kartarı, 2017, p. 212; Merriam, 2013, p. 14). Denzin and Lincoln (2005) used the expression "qualitative researchers study phenomena in their natural environment and thus understand phenomena or interpret what meanings people give to them" for qualitative research.

The following question was emphasized in order to achieve the primary goal established within the scope of the research.

> How is the future of the current business models, which are influenced by the technological developments that come with the Industry 4.0 transformation, from the perspective of sustainability?

Based on this research question and the literature, questions were prepared for the participants in the interviews. The interview texts were analyzed on the basis of topics such as Industry 4.0 transformation, its expected effects on business models, organizational sustainability, organizational efficiency, and adaptation of business models to changing conditions.

The purpose of this conceptual study is twofold. First, it aims to provide a comprehensive and integrated understanding of the intricate relationship between the Industry 4.0 revolution and organizational sustainability. By synthesizing existing theories, models, and empirical evidence, this study aspires to offer a holistic framework that elucidates how the adoption of Industry 4.0 technologies influences the economic, environmental, and social dimensions of organizational sustainability. Second, this study endeavors to contribute innovative insights to the academic discourse by leveraging the conceptual framework to explore uncharted territory within the problem domain. It seeks to identify novel perspectives and approaches that not only enrich the current literature but also provide practical guidance to businesses and decision-makers navigating the evolving landscape of Industry 4.0. In doing so, the conceptual study aspires to bridge the gap between theory and practice, offering valuable implications for both academia and the business world.

Basically, in qualitative studies, there are three different types of interviews: structured, semi-structured, and in-depth interviews. All

three interview methods are used in studies conducted for different purposes. While a structured interview is more suitable for a descriptive or explanatory research, a semi-structured interview seems to be more suitable for explanatory researches (Saunders et al., 2009, p. 318). The most widely used qualitative method is the semi-structured interview method. This method provides flexibility to the researcher. Although the researcher has a list of questions and themes to be addressed, questions may change as they move from one interview to the next (Bryman et al., 2011, p. 14). At the same time, this method has the ability to explain important aspects of human behavior, because with a semi-structured interview, answers to not only "what" and "how" but also "why" questions can be revealed. For this reason, researchers prefer semi-structured interviews to further explain the factors examined while evaluating the data (Aydın, 2021, p. 140; Qu & Dumay, 2011, p. 246).

In the course of this study, a qualitative research methodology was employed to investigate the research questions and objectives. Qualitative research is a robust and widely adopted approach that is particularly well-suited for exploring complex phenomena, such as the impact of Industry 4.0 technologies on organizational sustainability (Creswell & Poth, 2016; Denzin et al., 2023; Rossman & Rallis, 2016). It allows for a deep understanding of the experiences, perspectives, and insights of the study's participants.

The primary data collection method utilized in this study was semi-structured interviews. Semi-structured interviews provide a flexible and open-ended approach, enabling researchers to gather rich and contextually relevant data from the participants (Gubrium & Holstein, 2002; Kvale & Brinkmann, 2007; Rubin & Rubin, 2011). This method involved a well-defined set of open-ended questions, allowing for consistency in data collection while also permitting participants to elaborate on their responses. The selection of semi-structured interviews aligns with the research's qualitative nature, as it fosters in-depth exploration of the subject matter and encourages participants to express their opinions and experiences.

In the interviews, "real" and "deep" meanings can be deduced from the answers given by the interviewers, besides their superficial meanings. With this method, the possibility of weeding out insincere answers arises. The researcher has the opportunity to illuminate every dark spot he/she encounters during the interview with the questions he/she will ask immediately (Karasar, 2013, p. 166). Within the scope of this research, the possible effects of Industry 4.0 transformation on business models were tried to be determined from the perspective of organizational sustainability, and it was deemed appropriate to make a qualitative application with the semi-structured interview technique, since it was aimed to examine the views of the participants in a more thorough and comprehensive manner.

The use of semi-structured interviews contributes to the academic rigor of the research by offering insights directly from the individuals involved in and affected by the phenomenon under investigation. By engaging with participants in this manner, the study seeks to capture their unique viewpoints, experiences, and perceptions, thereby enriching the data and providing a deeper understanding of the complex interplay between Industry 4.0 technologies and organizational sustainability (Flick, 2017; Fontana & Frey, 2005; Seidman, 2006). The qualitative nature of the research design ensures that the study's findings are rooted in the real-world experiences and perspectives of those at the forefront of Industry 4.0 adoption, offering valuable insights for both academia and practical applications (Table 1).

3.2 | Sample and participants

The research employed a non-probability purposive sampling method. In the realm of qualitative research, where data collection predominantly hinges on interviews and observations, working with a large sample group is often impractical, given constraints related to time and cost. Qualitative research, instead, strives to paint a holistic picture that encapsulates the diverse, rich, distinct, and at times contradictory aspects of the universe under study without being bound by the concern of generalization. Qualitative researchers favor non-probability purposive sampling due to its capacity to facilitate a thorough exploration of information-rich situations. In the selection of sample participants, the emphasis lies not in their ability to represent the entire universe but rather in their direct relevance to the research subject (Neuman, 2012, p. 320; Yıldırım & Şimşek, 2008, p. 87).

While determining the participants to be included in the sample of the research, the criterion of the country and the number of employees of the organizations in which the individuals are active was evaluated as a prerequisite. In this context, it is primarily aimed to select the organizations that the participants work from among large-scale enterprises. In the literature, enterprises with more than 250 employees are considered as large-scale enterprises (Mecek, 2020, p. 47; Soydal, 2006, p. 541). This situation means that the individuals included in the sample are middle and senior managers in order to make a healthy assessment on the subject; in addition, it is due to the importance that the organization they work for is a large-scale enterprise in order to create the opinion that the participants have enough experience and knowledge on the subject. For this reason, before the interview, it was confirmed whether the relevant branch of the organization in which the activity was carried out had the desired number of employees and the interview started after that (Criterion A).

The second important criterion for determining the sample is whether the country in which the organization operates has the qualifications specific to the subject. For this reason, while determining the organizations included in the sample, an evaluation was made according to certain criteria of the country where the organization operates and/or is centrally affiliated. In this context, 100 countries and their economies representing more than 96% of the global Market Value Added (MVA) and Global Gross Domestic Product (GDP), according to a report by the World Economic Forum, were analyzed. As a result of this analysis, countries were grouped and 25 countries came to the fore according to the conditions of "Ready for the Future in terms of Production Evaluation Results" created with certain criteria (WEF, 2018, pp. 11–12). These countries, Austria, Belgium, Canada, China, Czechia, Denmark, Estonia, Finland, France, Germany, Ireland, Israel, Italy, Japan, Republic of Korea, Malaysia, Netherlands, Poland, Singapore, Slovenia, Spain, Sweden, Switzerland, the United Kingdom,

and the United States, were used in the selection of businesses included in the sample (Criterion B).

Another criterion (Criterion C) used in the selection of the countries where the research is aimed to be carried out within the sample is formed by ranking the countries according to the "Technology Achievement Index (TAI)." In this context, countries were classified according to the technological development index and the countries included in the study in this research sample were those in the

TABLE 1 Leading countries by technology achievement index.

TAI rank	Country	Number of patents granted to residents (per million)	High-tech exports (percentage of exports produced)	Technology production index score	Spreading of innovations index score	TAI total score
1	Switzerland	366.48	26.84	0.842	0.697	**0.813**
2	Luxembourg	368.63	6.82	1	0.559	**0.766**
3	Holland	117.97	19.90	0.568	0.660	**0.745**
4	Sweden	197.88	14.26	0.427	0.593	**0.685**
5	Ireland	58.18	26.76	0.363	0.654	**0.682**
6	Singapore	22.58	49.28	0.136	0.877	**0.673**
7	Denmark	122.97	15.96	0.231	0.640	**0.666**
8	South Korea	39.26	26.84	0.074	0.708	**0.661**
9	Germany	173.46	16.66	0.266	0.599	**0.658**
10	USA	46.51	19.01	0.131	0.551	**0.635**
11	Finland	135.72	8.73	0.261	0.552	**0.633**
12	Norway	49.85	20.52	0.084	0.685	**0.626**
13	France	81.32	26.85	0.149	0.680	**0.622**
14	Japan	83.37	16.78	0.164	0.631	**0.619**
15	Austria	120.89	13.35	0.182	0.548	**0.617**
16	Australia	13.88	13.51	0.024	0.553	**0.616**
17	Belgium	76.73	13.02	0.154	0.551	**0.604**
18	Israel	47.37	19.66	0.087	0.581	**0.597**
19	New Zealand	11.1	9.62	0.026	0.536	**0.596**
20	Malta	44.05	31.90	0.175	0.682	**0.589**
21	Iceland	84.64	19.90	0.237	0.687	**0.582**
22	Estonia	7.62	11.40	0.011	0.554	**0.576**
23	Kazakhstan	0.23	41.19	0.000	0.751	**0.575**
24	Russia	0.53	13.76	0.001	0.496	**0.563**
25	Greece	2.03	10.99	0.003	0.434	**0.562**
26	Czechia	7.01	14.90	0.017	0.549	**0.557**
27	Slovenia	31.5	6.42	0.047	0.425	**0.556**
28	Hong Kong	3.7	10.71	0.005	0.529	**0.549**
29	UK	32.19	20.81	0.091	0.662	**0.546**
30	Malaysia	0.73	42.80	0.001	0.757	**0.536**
31	Lithuania	3.78	11.85	0.006	0.467	**0.535**
32	Spain	11.25	7.15	0.021	0.462	**0.534**
33	Latvia	4.04	15.05	0.006	0.539	**0.531**
34	Slovakia	2.03	10.29	0.003	0.525	**0.526**
35	Poland	3.95	8.78	0.007	0.420	**0.522**
36	Belarus	0	4.31	0.000	0.346	**0.521**
37	Hungary	3.86	13.74	0.032	0.492	**0.516**
38	Italy	40.72	7.34	0.064	0.393	**0.507**
39	Argentina	0.3	9.01	0.001	0.429	**0.506**
40	Canada	21.09	13.83	0.048	0.577	**0.506**

"Leading Countries" group (Ağan, 2022, p. 259; Incekara et al., 2017, p. 169).

These leading countries, included in the country selection sample and leading, today constitute more than three quarters of the "Global Manufacturing Value Added" (WEF, 2018, pp. 11–12). For this reason, they took part in the selection of the sample with the thought that these are the countries that are expected to be pioneers in new production technologies and/or should be consulted for a healthy evaluation of industrial transformation. In this direction, middle and senior managers working in businesses that meet the above-mentioned criteria in the selection of the sample of the research and the participants to whom the interviews will be conducted were included in the research. For a better understanding of the criteria used in the selection of the sample, the figure below can be consulted (Figure 1). It has been tried to discuss the evaluations of the participants, who work in different fields, take different roles and positions, operate in different units, are known as pioneers or guides in the relevant field, and follow the subject in the written or visual media, about the research topic and questions of the research.

3.3 | Instruments

A semi-structured interview form was used in the research. In the form, questions were asked that were thought to allow the desired information to be obtained in order to understand the subject in more detail and in depth. Several interviews with the 24 participants incorporated into the study were conducted in person by the researcher before the onset of the Covid-19 pandemic. These face-to-face interviews took place in countries situated on the European continent. However, with the advent of pandemic conditions, travel restrictions rendered it unfeasible to conduct in-person interviews with participants on continents other than Europe. Consequently, interviews with these individuals were conducted via virtual mediums, encompassing both video and audio interviews. The engagement with participants was initiated with an initial contact through email, following which contact information was obtained, and the participants were included in the research via audio or video calls. It is essential to acknowledge that due to various limitations, not all countries were within reach for this virtual engagement. Consequently, the research was unable to encompass participants from every country that fulfilled the specified criteria. This situation constitutes one of the limitations of the study, and demographic information of the participants can be seen in Table 2.

As can be seen in the table above, the oldest of the research participants is 63 years old and the youngest is 23 years old. In this context, it can be said that participation in the research covers a wide age range. In addition, it is seen that the participants have reached a wide range in terms of years of experience in their sectors. The most experienced participant has 36 years of industry experience in the field, while the least experienced participant has 1 year of experience in the sector. Germany and Czechia stood out as the countries with the highest participation, with three participants each. The acceptance of Germany as a country as the starting point of the concept of Industry 4.0 can be considered as the reason for this situation and as an indicator of how Germany attaches importance to the subject as a country. Moreover, at this point, it is striking that Czechia is both willing to work on the subject and is enthusiastic about catching up with the

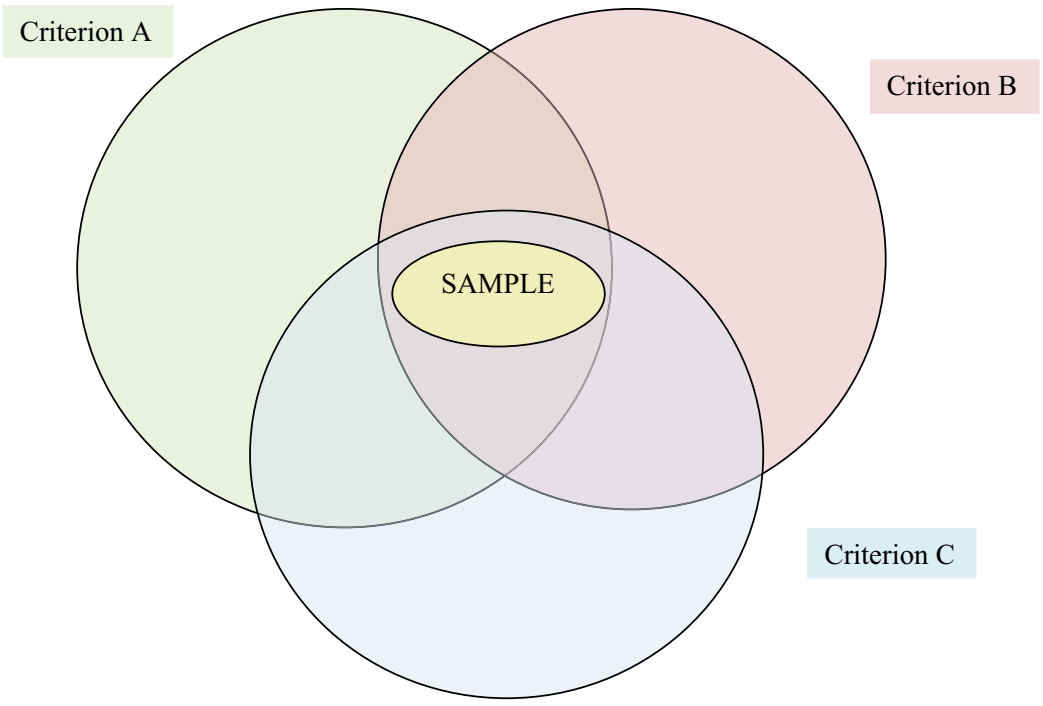

FIGURE 1 Criteria used in sample selection.

TABLE 2 Demographic information of participants.

Participant	Age	Gender	Graduation	Position	Country	Experience
1	34	Female	Bachelor	Senior Manager	Germany	13 Years
2	63	Male	Bachelor	Senior Manager Assistant	Poland	36 Years
3	46	Female	Bachelor	Senior Manager	Singapore	20 Years
4	30	Male	Master	Senior Manager	Malaysia	6 Years
5	42	Male	Bachelor	Senior Manager	Czechia	18 Years
6	39	Male	Master	Senior Manager	France	15 Years
7	51	Female	Master	Manager	Czechia	27 Years
8	28	Female	Bachelor	Manager	France	5 Years
9	29	Male	Bachelor	R&D Specialist	Austria	4 Years
10	27	Male	Bachelor	System Engineer	Czechia	3 Years
11	34	Female	Bachelor	Expert Engineer	Poland	8 Years
12	25	Male	Bachelor	R&D Specialist	Germany	1 Year
13	30	Male	Bachelor	Design Engineer	Holland	5 Years
14	33	Male	Master	Research Assistant	Germany	5 Years
15	45	Male	PhD	Senior Manager	Singapore	21 Years
16	23	Female	Master	Manager	USA	3 Years
17	47	Male	Bachelor	Manager	Malaysia	25 Years

changing technology. On the other hand, 35.3% of the participants, or six of them, are women, and 65.7%, or 11 of them, are men. Moreover, when the educational status of the participants is examined, it is seen that the majority of them have a bachelor's degree (64.7%), while the other six participants consist of one doctorate and five master's degrees.

Throughout the interview process, participants were initially provided with comprehensive information pertaining to the research's subject matter and its overall scope. Emphasis was placed on underscoring the significance of the study, and participants were explicitly requested to respond to inquiries objectively and candidly, adhering to the fundamental principle of voluntariness. Given the linguistic diversity inherent to the researcher and the participants within the research sample, a prerequisite was established for the interviewees, ensuring a proficient level of English-speaking competence. As a common language mutually accessible to both the researcher and participants, the interviews were consequently conducted in English, leveraging the researcher's fluency in the language.

The study, initially, aspired to encompass participants from a diverse array of countries within the research sample. However, the practical realization of this objective was constrained to select countries due to considerable challenges, primarily of material and ethical nature. It is noteworthy that this research was conducted independently, without any external institutional support. Concurrently, an additional noteworthy observation surfaced during the course of this study; distinct attitudes and priorities were discerned among organizations across various countries included in the research sample concerning Industry 4.0. While certain countries demonstrated a cooperative disposition and attributed substantial significance to the tenets of Industry 4.0, conversely, some exhibited a contrasting stance. The pronounced participation from Germany, which stands as the conceptual genesis of the Industry 4.0 framework, further substantiates this divergence. Moreover, this phenomenon, bearing implications for future research and discourse, could be contemplated as a distinct research topic warranting exploration in forthcoming studies.

3.4 | Analysis and interpretation of data

The qualitative analysis process is a systematic approach employed to categorize data into coherent groups, thereby facilitating the identification of specific themes that emerge from these categories. Subsequently, these themes are cross-referenced with the data to determine the need for further review. Ultimately, the researcher assumes the task of interpreting the participants' perceptions and reporting the findings using their own words (Aydın, 2021, p. 145; Eatough & Smith, 2017). In the context of this research, the data obtained underwent a meticulous analysis using both content analysis techniques and the qualitative research program, Nvivo. Content analysis involves a four-stage process, commencing with data coding, followed by theme identification, organization of both codes and themes, and culminating in the interpretation and reporting of the findings (Yıldırım & Şimşek, 2008, p. 243). The data analysis process, under the careful supervision of the researcher, transpired through a systematic sequence of discrete phases. Commencing with the transfer of audio recordings and interview documents to a computerized platform, these materials underwent meticulous scrutiny. A diligent review process ensued, where the content was meticulously dissected and demarcated into meaningful segments within the qualitative research software. Each section was then subjected to a coding

process, illuminating its underlying conceptual significance. As commonalities began to surface among these codes, the data were judiciously categorized, contributing to a coherent organizational framework. Subsequently, to ensure a comprehensive comprehension of the findings, these codes and thematic patterns were subject to interpretation, further enriched by the integration of direct quotations extracted from the interview transcripts within the analytical procedure. An example of data analysis process can be seen in Table 3.

In the process of selecting research participants, an inclusive approach was deliberately adopted, taking into account a spectrum of key demographic factors including age, gender, educational background, occupational position, nationality, and industry experience. This comprehensive representation of participant diversity facilitated a comprehensive exploration of the potential effects of these variables on the research outcomes. To ascertain the appropriate number of interviews for the study, meticulous adherence to the principle of "reaching data saturation" was observed. Data saturation, serving as a pivotal criterion, is attained when the researcher can no longer extract novel information from participants, resulting in a discernible repetition of themes within the interviews. Upon recognizing this stage, a limited number of supplementary interviews were conducted, serving to validate the achievement of data saturation. This validation was integral to bolstering the robustness of the research findings. Furthermore, the decision was made to conduct a higher number of interviews, ensuring the accumulation of a substantive volume of data. The interviews were formally concluded only when control interviews subsequently confirmed the attainment of data saturation. This approach not only fortifies the validity of the research but also contributes to the depth of the findings. During the interviews, coding was performed based on the participants' responses, and their anonymity was strictly maintained in adherence to scientific ethics (Büyüköztürk et al., 2018). Prior to the interviews, explicit consent was obtained from all participants, and ethical compliance with principles and human rights was ensured through the decision of the Ethics Committee of Süleyman Demirel University (Isparta/Türkiye), reference number E-87432956-050.99-78861.

In summary, the diligent qualitative analysis process employed in this study underscores its commitment to rigorously exploring the perspectives of the participants, thereby enhancing the scholarly integrity of the research. This rigorous analytical approach effectively addresses the central research question pertaining to the influence of Industry 4.0 on business models within the sustainability framework. By engaging with a diverse array of perspectives and experiences, the research furnishes comprehensive insights that significantly enrich the expanding body of knowledge in this domain. These insights, in turn, augment the practical relevance and applicability of the research findings in both academic and business spheres, underlining the study's broader significance and resonance. In the subsequent section of this inquiry, we shall expound outcomes of the research. Delving into a comprehensive exploration of these results will provide a nuanced understanding of the intricate dynamics at play between Industry 4.0 and the evolution of sustainable business models. The forthcoming elucidation of these findings will serve to illuminate the transformative potential that Industry 4.0 holds within the sustainability framework. It is within this context that we will discern not only the challenges and opportunities presented by this digital industrial revolution but also its implications for innovating and redefining sustainable business practices in contemporary industries.

4 | FINDINGS

When examining technological advancements spanning from the past to the present, it becomes evident that a profound and intricate relationship exists between these advancements and the evolution of business models. This connection stems from the fact that technological developments, often instigated by industrial revolutions, have consistently precipitated shifts in the structure and strategies of business models. Each industrial revolution has engendered distinct outcomes that are inextricably tied to the conditions of their respective eras. Notably, technological innovations have yielded both advantageous and detrimental consequences for various business models. In this context, the Industry 4.0 revolution, which has garnered substantial attention in recent literature, ushers in a new era of digital transformation characterized by the introduction of advanced technological components. These Industry 4.0 components serve as pivotal determinants shaping technological progress within the context of this digital transformation era.

The concept of Industry 4.0 has garnered substantial scholarly attention, particularly in recent years, leading to numerous international and national studies that have explored the multifaceted dimensions of Industry 4.0 and its organizational implications. These

TABLE 3 Data analysis process.

Themes	Subthemes	Raw data	Researcher's comment
Question: You mentioned about the efficiency. How do you think Industry 4.0 will affect this situation?			
When the Industry 4.0 transformation is completed, what are the possible effects and outputs of this transformation on today's business models?	The expected possible impact of Industry 4.0 transformation on existing business models.	*Industry 4.0 enables the collection and analysis of every single data in the production environment. Thus, it creates more efficient business models.*	With this answer, the participant emphasizes that with the development of Industry 4.0 technologies, every data in the production environment will be collected and analyzed, and in this way, today's business models will be more efficient.

investigations encompass a spectrum ranging from theoretical examinations to empirical research that delves into the practical effects of Industry 4.0. Within this realm, this section undertakes an assessment of the various studies that scrutinize the impacts of Industry 4.0 on diverse facets of business models, especially through the lens of sustainability. As existing literature takes multifarious approaches to understanding the multifaceted concept of Industry 4.0, this research adopts a comprehensive perspective, structuring its data analysis along the axes of themes and codes that arise from interviews and literature reviews.

As technology undergoes constant transformation and development, critical questions regarding the future of organizational production processes and practices, the adaptation of organizational resources to dynamic conditions, and the evolving role of human resources within organizations are becoming increasingly pervasive. Consequently, the nexus between sustainability and Industry 4.0, which serves as the core inquiry of this research, has garnered the attention of numerous scholars within the existing literature. In this section, we contemplate how the advent of Industry 4.0 in the future will engender transformations within organizations, specifically from a sustainability-oriented standpoint. We delve into studies that explore the intricate interplay between the concept of Industry 4.0 and the realm of sustainability, aiming to offer an evaluative perspective on the ensuing changes and their implications on business models.

Sustainability, in general terms, refers to the capacity to sustain a situation or process for an indefinite period (Yavuz, 2010, p. 64). Sustainability has become a frequently used concept due to environmental problems such as climate change and global warming, which have been felt in recent years (Suganthi, 2020, p. 11). For a more livable and resource-free world, the systems used in production activities should contribute to the sustainability of resources. The components of Industry 4.0, which cause serious transformations in production systems, can be seen as an important opportunity to ensure organizational sustainability. In a system where smart factories dominate the production processes, the sustainability of natural resources will be easier (Gültekin & Argon, 2020, p. 508). Machines talking to each other will reduce the amount of defective production and can prevent waste of resources. Thanks to Industry 4.0, the units in communication with each other will optimize the demands of the relevant departments in real time, and cost, pollution, raw material use, and carbon emissions will be reduced (Akaev & Rudskoi, 2017; Comin et al., 2019; Özenir & Nakıboğlu, 2019, p. 2271). Therefore, renewed business models will provide a competitive advantage in improving the sustainability performance of organizations because the concept of a sustainable business model defines the logic of how an organization creates, transmits, and achieves value in an economic, social, environmental, or other context in a sustainable way (Bocken et al., 2019, p. 1498; Nosratabadi et al., 2019).

A systematic literature review was made, and a roadmap proposal for sustainable development was presented in which Industry 4.0 applications for sustainable production were discussed in a research held by Ching et al. (2022). As a result of the research, the authors determined that Industry 4.0 contributes to sustainable production through 15 highly interrelated functions. These functions are renewed business models, customer-oriented production, employee productivity, harmful emission reduction, improved profit margin, smart production planning and control, production agility, productivity and efficiency, new employment opportunities, resource and energy efficiency, reduced production costs, safe and smart working environment, supply chain integration, sustainable product development, and sustainable value creation network. According to the authors, these functions have important effects on production processes and affect the organizational structure in almost every sense. However, the most striking point in this research is the author's emphasis on renewed business models.

When a general review of the subject is made in the literature, it is seen that the studies that deal with the effects of technological developments on sustainability in economic terms are in the majority. Brynjolfsson et al. (2014) state that a productivity increase is expected with the use of productivity and efficiency-oriented new techniques developed through Industry 4.0 technologies in production. There are also studies emphasizing that the developments in productivity and efficiency in new technologies, capital-intensive production processes, and flexible management styles cause economic growth (Belgin, 2010, p. 115; Çondur et al., 2016; Dobrowolska & Knop, 2020; Kureş & Şık, 2022; Mukhuty et al., 2022, p. 2068; Wisskirchen et al., 2017), because productivity, flexibility, and increased continuity in quality are of great importance for the manufacturing industry. In this context, there are studies in the literature that mention the importance of the effect of digitalization on production processes for the future of organizations (Atilla et al., 2019; Çalış Duman, 2022, p. 189; Dengiz & Belgin, 2007, p. 267; Evans et al., 2017, p. 605; Prinz et al., 2016). The productivity and efficiency emphasis of the participants is similar to the literature:

> Experts say that in the future production systems will be faster and more efficient. I think artificial intelligence is important in this respect. Artificial intelligence means machines do more and faster work on their own. These are very important today. Speed and efficiency. (Participant 3/Singapore/Senior Manager)

> I think the current production system is slow, it can be faster. I've seen it in the countries I've been to. They produce faster than us and they do it with machines. It's faster, more productive, cheaper because robots do all the work. There are simple machines. They do the same things over and over again. They can work around the clock and another thing that surprises me is that they produce more than us with almost half the space of the production line we set up. (Participant 4/Malaysia/Senior Manager)

> In my opinion, the most important benefit of technological developments will be in terms of cost. Because with the advancement of technology, raw material extraction has become easier, energy production is

> now easier. For example, electricity can be generated with solar panels. Every development in technology reduces the cost of production. In addition, there is a fast production now, the machines do not get tired, they do not take breaks for lunch, they work constantly. Since the production does not stop, it is efficient and fast. Speed is very important nowadays. The more we produce, the faster we can sell. This is true for our company as well as for our country. (Participant 6/France/Senior Manager)

> In my opinion, the most important return of Industry 4.0 will be efficiency. I think that in the future production will be more efficient than today. This can be possible with technology. Speed is also very important. An efficient and fast production. (Participant 15/ Singapore/Senior Manager)

As the development of Industry 4.0 technologies causes the robotic workforce in production to become more attractive than workers in terms of productivity and wages, it is among the findings obtained in a research that developing countries as well as developed countries will affect the labor market (Javelosa, 2017). In this context, in other studies approaching the subject, it is thought that technological developments will increase labor productivity, reveal new job skills for new business groups, and increase employment for skilled workers when their important role in economic growth is taken into account (Fırat & Fırat, 2017). In addition, it is stated in other studies that with the completion of digital transformation, new employment opportunities will be created based on new technologies in the medium and long term (Aksoy, 2017; Becker & Stern, 2016; Castells, 2008; Fırat & Fırat, 2017; Kabaklarlı, 2016; Koca, 2018; Lorenz et al., 2015; Weyer et al., 2015; Wisskirchen et al., 2017). Some of the research participants have similar views with the literature on this issue:

> I do not think that the people whose jobs are taken by the machines will be unemployed. There are enough jobs in Germany. These people can find other jobs, and new jobs may emerge. Because, every new technology means a new job. For example, a machine comes and the technical staff (technician) of that machine is hired, there are people to help the engineers. (Participant 1/Germany/Senior Manager)

> People think that when robots multiply, they will lose their jobs, but I think it will be the other way around. In a research conducted in Germany, employment increased by 6% in the industrial field after five years of Industry 4.0 investment. This means that with Industry 4.0, new business areas have emerged, that is, unemployment has not decreased, on the contrary, it has increased. We, as a business, have increased our digitalization and almost doubled our production in the last 2 years, and the most important point here is that we have not laid off anyone. People my age know that in the 90s, when computers started to take over the business, people were scared. They said computers came, we will be unemployed and they discussed it for almost 10 years. However, the opposite of what we thought happened, today computers provide jobs for millions of people in the software and hardware field. These jobs did not exist 30 years ago. (Participant 2/Poland/Senior Manager Assistant)

> As technology develops, new business areas emerge, I think, this is an opportunity. (Participant 11/Poland/ Senior Engineer)

> Considering the old days, we have now come to a very advanced level. Technology has developed a lot, production has advanced a lot. 2 people can do the job that used to be done by 5 people. We can produce more efficiently and faster with less resources. Isn't that the most important thing for production anyway? Getting a lot of output with less resources. Technology is giving us this right now. Unemployed people find other jobs. They work better for them. Because with new technologies, new jobs are emerging. (Participant 15/ Singapore/Senior Manager)

The increasing flexibility of production systems with the developing technology enables products that can be designed and produced in small batches according to customer demands. In this context, organizations aiming to adapt to changing production conditions should take this situation into account and make the necessary arrangements (Mijatovic et al., 2020). It is important in terms of waste of resources that production systems have a more flexible structure and that this flexibility can be applied in small batches of production. Products that can be processed in more detail and in small pieces have less waste and provide significant advantages to businesses in terms of sustainability (Bilgin, 2021, p. 141; Dentchev et al., 2018, p. 695). In this respect, new and existing companies must find ways to thrive in a competitive environment with innovative business models, while both respecting society and avoiding actions that harm the environment in which they operate. When it comes to radical re-evaluation of production processes, it will be possible to benefit from high technology and when a viable business model is found, technology will be beneficial in terms of developing business models (Hecklau et al., 2016; Mete, 2018, p. 1066; Todeschini et al., 2017, p. 759). In this context, one of the participants interviewed within the scope of the research expressed her views as follows:

> Technology exists to help people. Together with the machines, we can produce faster. We can produce better quality. We must produce better quality so that the consumer should choose us. Also, the idea of uniform

> production in the world is coming to an end. This is one of the goals of Industry 4.0. The consumer now wants to be special, they want to feel it in everything they pay for. This is one of the innovations of the future. Fast, large-scale production with small, tailor-made details. Wouldn't you like to design the car you will buy from your computer at home and receive it from the factory in this way? I think this will be possible with Industry 4.0. Massive but flexible production. A production that people can touch. (Participant 7/Czechia/Manager)

Matos and Silvestre (2013, p. 61), while updating business models, not only environmental and economic factors, also state that many factors such as technological, cultural, and social should be taken into consideration. In this context, organizational sustainability is related to compliance with human rights, attention to improvement of working conditions and employment age, gender, etc. It has an important role in issues such as ensuring fair distribution among social classes and equal sharing of consumption opportunities (Bilgin, 2021, p. 141).

Demirkol and Tis (2018) discussed the effects of Industry 4.0 on HRM by addressing how human resources have developed from past to present. As a result of the research, it was concluded that the most important issue in terms of compliance with Industry 4.0 is education. The author has made a number of suggestions that can be applied at this point. Among these suggestions, there are suggestions such as giving lessons on coding in schools from an early age, establishing robotic clubs, various competitions and projects, and enabling students to meet this new world early. In addition, the importance of raising individuals with a planned education in which they can gain not only theoretical but also practical experiences in an education system compatible with Industry 4.0 during their university period was emphasized. The author explained this situation by saying that "the organizations' adopting the concept of lifelong education and determining their policies in line with this goal will both contribute to their sustainability and be beneficial in terms of adapting to Industry 4.0."

This situation emphasizes the impact of technological developments on the social aspect of sustainability. In the literature, there are many studies that address the importance of education in terms of organizational sustainability. Organizations aim to improve the personal qualities of the employees as well as their careers with their training activities. In this respect, it is necessary to continuously train the workforce in order to have the necessary qualifications to achieve organizational goals, especially concepts such as increasing the ability to cope with stress, workload, and conflicts (Küsbeci & Tekin, 2021; Pereira, 2019; Strohmeier & Piazza, 2015). In this context, stakeholders and interested parties should focus on sustainable education activities in order to prepare for the new period and start shaping the future from today (Demirkol & Tis, 2018; Rouiller, 2018). Some of the participants interviewed within the scope of this research also have thoughts in line with this view:

> If we grow as a business, we will need more workers. We need more and better workers. More educated. For this, we provide trainings to our current employees. To develop our capacity. To have more educated workers. We support them. They too must adapt to the new era. (Participant 5/Czechia/Senior Manager)

> The existing workforce will be adapted to the change process through training. (Participant 13/Netherlands/Design Engineer)

> Robots cannot learn to work with us. We code them and they do what we want. That's why people need to learn to work with robots. Therefore, employees need to be trained. (Participant 15/ Singapore/Senior Manager)

> There is talk of a technology-based advancement. Concepts such as artificial intelligence, cloud computing and the internet of things are discussed. This is important for our world. It has become very popular in recent years. As a business, we organize trainings for our employees to improve themselves. (Participant 16/USA/Manager)

In addition, administrative practices will also have their share of change in terms of transforming the business models of organizations into a more sustainable structure. It is among the prominent findings in the literature that human resources employees can allocate more quality time to issues such as strategic human resources, career planning, employee engagement, and this contributes positively to the productivity of human resources employees, as routine work is digitalized with the effect of digitalization in human resources. In addition, this situation will allow employees to become more socially satisfied and less stressed individuals within the organization (Göktaş & Çetinceli, 2017, p. 721; Kırılmaz, 2020; Kucharcikova et al., 2021; Negiz et al., 2011, p. 213; Rafique et al., 2021). In this context, researchers emphasize that organizations should be aware of this change and transformation and adapt their human resources practices to this digital transformation. One of the participants of the research expressed her views on this subject with the following words:

> We organize continuous training within the company. We bring experts and hold information meetings with them. That's what we're here for as a group. I mean the human resources department. People think our job is just to hire employees, but that's wrong. We are also responsible for the development of the employees of the enterprise. How can I explain …. For example, if our employees or one of our employees do one hundred units of work, we, as human resources, are also working to increase this. We take care of everything

> about the employees. As employee benefits increase, the business becomes happier and performs better. This means fewer problems. (Participant 8/France/Manager)

Another prominent dimension of organizational sustainability is the relationship of the organization with the environment in which it is located. It is not possible for organizations to act independently of the environment they are in and to completely eliminate their interactions with their environment. In this context, organizations are living beings that interact with their environment (Lozano, 2018, p. 1164). Organizations need to adapt to technological changes in order to maintain their productivity increase and respond to environmental demands, and the said adaptation process will only be possible with a planning that will be implemented starting from today. Within the scope of this planning, organizations will be sustainable by integrating human, robot, and environmental elements, which are the basic features of the organizational structure that will change, into current business models and business models being strategic and proactive (Adamkova, 2020; Çetin, 2021; Demirbağ & Yıldırım, 2022, p. 218). In this context, two of the research participants expressed their thoughts as follows:

> I think the most important issue is efficient production. I said that we produce more efficiently with the same resources. We produce efficiently and at the same time faster. These two things make us stronger against our competitors. Although the work we do is doubled, we do not experience any loss of quality. Our capacity is increasing. The competencies of our employees are increasing. Our current workforce is now able to adapt to new technologies. We provide training for this. Thus, the quality of our employees as an institution has increased. We have employees who can work with new technology. (Participant 2/Poland/Senior Manager Assistant)

> Industry 4.0 is exactly that. The development of machinery used for production. Like a cell phone. We can now do the work that was done with 3–4 machines in the past with a single machine. It can be called autonomous robots or artificial intelligence. As technology develops, newer production systems come out and faster production is made. We are planning to produce here in the same way as the rest of the world by bringing the newest technologies to our country. (Participant 4/Malaysia/Senior Manager)

Some of the researchers concluded that the creation of new business models for sustainable development is urgently needed and that this can be achieved in a joint effort with governments (Aydın, 2020, p. 234; Birkin et al., 2009, p. 75; Evans et al., 2017, p. 597; Gerged et al., 2023; Tirabeni et al., 2019). The research participants also have thoughts that overlap with this view. These thoughts are as follows:

> Government offices are in constant contact with us. When you ask for support, they give support. It sends experts for training. They tell our employees about Industry 4.0. They provide financial support in this regard. When we want to buy machines for factories, there is support for this. I think my country will be successful in this regard because we attach great importance to this issue. (Participant 9/Austria/R&D Specialist)

> Young people should be developed about these issues in schools. Because the future of the world is here. Our country provides support, but it could be better. (Participant 10/Czechia/System Engineer)

> Our country attaches great importance to education. There is an education policy for technology. It may be less now, but it is increasing. Not only for schools, we also provide training to our employees as a business. Our country supports us in this regard, provides financial support for education. (Participant 12/Germany/R&D Specialist)

> As a country, we consider the future very important. The future is very important to all of us. The Ministry supports us in this regard. Sends trainers so that we can train our employees. Provides financial support. Because our development as a country can only be possible with the development of individuals and businesses. That's why I can say that the whole country is working hard. (Participant 15/ Singapore/Senior Manager)

Increasing populations of countries and changing consumption habits trigger the increase in production. The increase in production leads to an increase in the production of industrial waste and the consumption of natural resources (Bilgin, 2021, p. 141). In this context, another important point that stands out within the scope of the research is the concept of circular economy. Adopting the circular economy requires innovative business models based on resource efficiency and closed material flow cycles. The idea of creating a sustainable life awareness by changing the consumption habits of the society by providing social and environmental advantages is at the basis of the circular economy. Today, many companies around the world are turning to circular product design strategies and business models to achieve sustainable solutions. In this respect, innovative business models are at the forefront of the elements that help to move toward sustainable systems (Godina et al., 2020; Türkmen & Kılıç, 2020, p. 2552).

Technological developments, on the other hand, will enable the implementation of more sustainable business model approaches by

using resources in a more sustainable way and reducing waste of resources in production processes (Açıkalın, 2020, p. 240; Dal Mas et al., 2020; Mercuri et al., 2021). In this way, more customers will be able to access environmentally friendly products with innovative business models (Wells, 2013, p. 234). Because, considering today's production methods, consumption habits, and future generations, the discomfort caused by the use of resources in the world and the sensitivity to environmental problems have increased among consumers (Koçan et al., 2019, p. 528; Yılmaz, 2020, p. 346). The research participants expressed their thoughts in this context as follows:

> With Industry 4.0, more integrated systems are emerging. Now we use one machine instead of 3–4 machines. Single machine consumes less energy. Think about it all over the world, globally. The resources of our already scarce world are not wasted. In this way, there can be progress around the world. Food for all, clothes for all. Equal conditions can be created for the whole world. (Participant 4/Malaysia/Senior Manager)

> Technological developments have many benefits, but the most important ones are more precise and more targeted production, a safer working environment, the ability to work remotely, greater efficiency and less energy consumption. In this way, environmental protection can be achieved. For example, less greenhouse gas production. I think it will benefit in this way and many more. (Participant 14/Germany/Research Assistant)

> A system that is more efficient and resources are used more effectively. (Participant 17/ Malaysia/Manager)

An industry's production success is related to how effectively it can transform its resources and add value to its participants in terms of cost, time, quality, and scope (Koralay & Halıcıoğlu, 2022, p. 238). Thanks to the "Internet of Things" and "Horizontal Integration" technologies, which are components of Industry 4.0, it will be possible to follow the product throughout its entire life cycle, starting from the production process as raw material to the final product and usage stage. In this way, systems that contribute to environmental sustainability such as the use of materials that are harmless to nature, reduction of resource and energy consumption, recycling, reuse, recovery, and reproduction can be utilized (Bilgin, 2021, pp. 141–142; Strandhagen et al., 2017, p. 359). In the interviews held within the scope of the research, the participants expressed the following in this regard:

> Industry 4.0 enables the collection and analysis of every single data in the production environment. Thus, it creates more efficient business models. (Participant 11/Poland/Expert Engineer)

> I can say that product tracking opportunities have increased with new technologies. With the advancement of artificial intelligence, every product produced will be followed at every stage. Where and what has been done will be followed. We can do that now, but with technology support, we can do it better in the future. (Participant 12/Germany/R&D Specialist)

Having presented the findings of this research, we now turn our attention to the critical phase of the discussion. The culmination of the diligent qualitative analysis has revealed a rich tapestry of insights, offering an in-depth understanding of the symbiotic relationship between Industry 4.0 and sustainable business models. In the forthcoming discourse, we will interpret these findings through the lens of theory and practice, dissecting the implications they bear on the domains of academia and industry alike. Our aim is to engage in a comprehensive examination of the transformative potential and challenges inherent to Industry 4.0's integration with sustainability, fostering a dialogue that bridges the theoretical underpinnings of this research with practical implications for businesses in today's rapidly evolving landscape.

5 | DISCUSSIONS

The research adopted a semi-structured qualitative interview approach, engaging middle and senior managers employed in companies situated within selected nations that fulfilled specific criteria. In the course of these interviews, participants were invited to express their perspectives on the potential ramifications of the Industry 4.0 revolution on their business models, with a particular focus on organizational sustainability. Subsequently, the interviews underwent thematic analysis, and the responses provided by the participants were scrutinized in conjunction with existing literature.

A noticeable observation emanates from the diversity of responses obtained from the participants regarding the fundamental subject of the research: the future of business models. Evidently, participants hold distinct viewpoints regarding the influence of technology on their current business models. This divergence in opinion stems from the historical backdrop of business models, which have continually evolved since the advent of the first industrial revolution. Moreover, research participants harbor the belief that technological advancements are poised to usher in economic growth, creating novel employment prospects. Within this context, organizations are encouraged to vigilantly track technological developments and align their business models accordingly, thereby paving the way for sustainable and efficient economic growth. In this regard, the research's outcomes and literature's results (Aksoy, 2017; Becker & Stern, 2016; Castells, 2008; Fırat & Fırat, 2017; Javelosa, 2017; Kabaklarlı, 2016; Koca, 2018; Lorenz et al., 2015; Weyer et al., 2015; Wisskirchen et al., 2017) are akin. Participants also mentioned the importance of technological developments in terms of organizational sustainability as they offer more flexible and personalized mass production opportunities. This is consistent with the findings of the literature (Bilgin, 2021; Dentchev et al., 2018; Hecklau et al., 2016; Mete, 2018; Mijatovic et al., 2020; Todeschini et al., 2017).

The research's participants' perspectives on sustainability are not confined to the economic realm. Some of the participants addressed the changes that the future industrial world will face in terms of societal and administrative aspects. Participants state that the workforce should be adapted to changing conditions in order to be both socially satisfied and increase its productivity. In addition, it is emphasized that human resources units should be developed both in order to adapt to changing conditions and to manage the development of the workforce. In this context, the findings of the research show that education has an undeniable role in empowering today's workforce. While daily and short-term policies may be sufficient for the education of the current workforce, it may be beneficial to develop regional, national, or global education policies at the point of training the future workforce. In this respect, the participants emphasize that organizational sustainability, as frequently mentioned in the literature (Bilgin, 2021; Demirkol & Tis, 2018; Küsbeci & Tekin, 2021; Matos & Silvestre, 2013; Pereira, 2019; Rouiller, 2018; Strohmeier & Piazza, 2015; Studer et al., 2006), should be seen as a government policy.

In addition, another important point mentioned by the participants is the importance of planning activities in terms of adapting to technological changes, updating business models, and gaining competitive advantage. In the literature, it is stated that organizations will be sustainable with the integration of human, robot, and environmental elements, which are among the basic features of the organizational structure that will change within the scope of planning, into current business models and if business models are strategic and proactive. In this respect, the findings of the research are in line with the literature (Adamkova, 2020; Çetin, 2021; Demirbağ & Yıldırım, 2022, p. 218).

Yet another result, and one of the most essential aspects of the study's main starting point, is the environmental sustainability of future business models. In this respect, the literature findings (Açıkalın, 2020; Dal Mas et al., 2020; Godina et al., 2020; Koçan et al., 2019; Mercuri et al., 2021; Türkmen & Kılıç, 2020; Yılmaz, 2020) and participant's perspectives are parallel to each other. The resources of the world we live in serve humanity as materials used in production processes. In this respect, it is our responsibility to ensure that these resources are processed in a more sustainable way.

Dealing with the challenges posed by Industry 4.0 has significant policy implications for the broader economy. The advent of Industry 4.0 technologies, characterized by the integration of digital, physical, and cyber-physical systems, presents a range of opportunities and challenges that require a strategic policy framework. Here, we delve into the academic considerations surrounding these policy implications:

- Investment in Digital Infrastructure and Education: To harness the benefits of Industry 4.0, policymakers must prioritize investments in digital infrastructure, such as high-speed internet and data storage, to ensure connectivity across regions (Rüßmann et al., 2015, p. 55). Additionally, an educated workforce is crucial. Policymakers should focus on digital literacy and retraining programs to equip the workforce with the skills required in the digital era (Brynjolfsson & McAfee, 2014). Some participants of the study (5, 12, 13, 15, 16) also expressed their opinions on this issue and emphasized the importance of education as can be seen in the findings part of the research.
- Regulation and Standardization: Policymakers need to strike a balance between fostering innovation and protecting consumer rights. Regulations and standards must evolve to address issues like data privacy and cybersecurity (Brousseau & Glachant, 2011, pp. 206–207). Harmonizing international standards is essential to facilitate global trade and interoperability (Jazdi, 2014, p. 4). None of the participants of the research mentioned this issue, so this is one of the key findings.
- Support for Small and Medium Enterprises (SMEs): SMEs often face barriers to adopting Industry 4.0 technologies due to cost and complexity. Policymakers can provide incentives, such as grants and tax benefits, to encourage SMEs to invest in digitalization (Akbar & Rashid, 2018, p. 196). Participant 2 and participant 7 also have views that support this issue.
- Reskilling and Workforce Adaptation: Industry 4.0 disrupts traditional job roles. Policymakers should encourage lifelong learning and adaptability in the workforce. Education and training programs that align with the changing demands of the labor market are vital (Davenport & Kirby, 2016). Two participants of the study (2 and 4) also expressed their opinions on this issue.
- Intellectual Property Protection: As technology advancements accelerate, intellectual property protection becomes more critical. Policymakers should ensure that the legal framework is robust to protect innovation and incentivize research and development (Lemley, 2015, p. 460). None of the participants of the research mentioned this issue, so this is also one of the key findings.
- Sustainable Practices: Industry 4.0 can have a significant impact on resource use and environmental sustainability. Policies should incentivize sustainable practices, such as energy-efficient technologies and circular economy principles (Lee et al., 2014, p. 8). In this study, there are participants (2, 4, 11, 12) who emphasize the importance of sustainability.
- Data Governance and Ownership: With the proliferation of data in Industry 4.0, questions of data ownership and governance arise. Policymakers must establish clear rules regarding data ownership, access, and usage to ensure fairness and transparency (Kshetri, 2017, pp. 1036–1037). None of the participants of the research mentioned this issue, so this issue is also one of the key findings.
- International Collaboration: Industry 4.0 is a global phenomenon. Policymakers need to engage in international collaboration to address cross-border challenges, such as data flows and cybersecurity threats (Reis & Gins, 2017, pp. 10–11). In this study, there are participants (9, 10, 12) who mention that international policies should be developed through governments.
- Infrastructure for Innovation Ecosystems: Policymakers should invest in innovation ecosystems, such as technology parks and incubators, to promote research and development in emerging technologies. These ecosystems are essential for nurturing startups and fostering innovation (Audretsch & Feldman, 1996, p. 639). In

this study, there are participants (4, 7, 14, 17) who emphasize the importance of the infrastructure for innovation ecosystems.

- Ethical Considerations: As autonomous systems become more prevalent, policymakers should address ethical considerations related to AI and robotics. Ethical frameworks and guidelines can help navigate the challenges of AI ethics and responsible AI development (Floridi et al., 2021, p. 38). None of the participants of the research mentioned this issue, so this issue is also one of the key findings.

In conclusion, Industry 4.0 presents both opportunities and challenges for the broader economy. Policymakers play a critical role in shaping the response to these challenges and leveraging the opportunities. By focusing on digital infrastructure, education, regulation, support for SMEs, workforce adaptation, and other key areas, policymakers can foster an environment where Industry 4.0 technologies contribute positively to economic growth and sustainability. With the discourse on findings and discussions having reached its conclusion, we now pivot toward the final phase of this research endeavor—the formulation of conclusive insights. In this segment, we distill the essence of our study and draw together the various threads of analysis to provide comprehensive conclusions. The subsequent section will encapsulate the key takeaways and implications arising from the amalgamation of theory and practice, offering a synthesized perspective on the influence of Industry 4.0 on sustainable business models and its broader ramifications.

6 | CONCLUSIONS

In this part of the research, a series of inferences and suggestions are made, and the obstacles and limitations encountered during the implementation of the research are explained. As a result, with this research, it has been determined that business models have begun to reshape with the technological innovations taking place more and more in the organizational production processes in today's industrial structure. The business model applied by organizations is an important actor in terms of organizational competitive conditions and should be updated according to the requirements of industrial conditions. For this reason, organizations have to adapt their business models to the requirements of the age in order to meet the increasing competition conditions and continue their activities. Here, first of all, the prominent results in terms of the results of the study are discussed under certain headings. These are:

- Disruption of Mass Customization:
  - **Shift in Production Paradigm:** The advent of Industry 4.0 technologies challenges the traditional notion of mass customization. It enables efficient, flexible production processes that can provide customized products on-demand, reducing the reliance on large-scale production and inventory.
  - **Reduced Economies of Scale:** Mass customization typically leverages economies of scale, but Industry 4.0 allows cost-effective small-batch or even one-off production. This shift can diminish the cost advantage of mass customization.
  - **Changing Business Models:** Industry 4.0 encourages a shift from selling physical products to offering personalized services and solutions. This shift can disrupt the traditional mass customization business model.
- Disruption of SMEs:
  - **Digitalization Costs:** The adoption of Industry 4.0 technologies often involves high initial investment costs, which can be a significant barrier for many SMEs, preventing them from embracing these technological advancements.
  - **Skill Gap:** SMEs may face challenges in attracting and retaining talent with the necessary digital skills to operate and maintain Industry 4.0 systems, limiting their ability to fully benefit from these technologies.
  - **Market Competition:** As larger corporations embrace Industry 4.0, they may gain a competitive advantage over SMEs. The efficiency and innovation offered by these technologies can lead to market consolidation, making it challenging for smaller players to compete effectively.
- Employment Implications:
  - **Skill Shift:** The adoption of Industry 4.0 technologies will necessitate a shift in workforce skills. While some traditional roles may become obsolete, new roles related to data analytics, AI, and automation will emerge. Training and retraining will be crucial to bridge this skills gap.
  - **Job Displacement and Creation:** The disruptive impact of Industry 4.0 on mass customization and SMEs could result in job displacement in certain sectors. However, it also has the potential to create new jobs in technology-related fields, such as data science and robotics.
  - **Evolving Labor Market:** As traditional business models transform, the labor market will evolve. Some roles may become more project-based or gig-oriented, while others may require hybrid skills that bridge technical and business domains.

In summary, the adoption of Industry 4.0 technologies can disrupt mass customization by altering production paradigms, reducing economies of scale, and changing business models. SMEs may face challenges related to digitalization costs, skill gaps, and market competition, while the employment landscape undergoes shifts, leading to changes in job roles, skill requirements, and the emergence of new employment opportunities as traditional models are disrupted by Industry 4.0 technologies. Dealing with the challenges presented by Industry 4.0 has substantial policy implications for the broader economy. As we navigate the impact of this technological transformation, policymakers must consider several key factors:

- **Investment in Digital Infrastructure and Education:** To fully harness the potential of Industry 4.0, governments should prioritize investments in digital infrastructure, such as high-speed internet and data storage, ensuring widespread connectivity. Additionally, they should focus on enhancing education and training programs

to promote digital literacy and equip the workforce with the necessary skills for the digital era.

- **Regulation and Standardization:** Policymakers need to strike a balance between fostering innovation and safeguarding consumer rights. Regulations and standards must evolve to address critical issues like data privacy and cybersecurity while harmonizing international standards to facilitate global trade and interoperability.
- **Support for Small and Medium Enterprises (SMEs):** SMEs often face barriers when adopting Industry 4.0 technologies due to their cost and complexity. Policymakers can provide incentives, such as grants and tax benefits, to encourage SMEs to invest in digitalization and remain competitive.
- **Reskilling and Workforce Adaptation:** The workforce must adapt to the changing demands of Industry 4.0. Policymakers should encourage lifelong learning and adaptability, offering education and training programs that align with the evolving job market.
- **Intellectual Property Protection:** As technology advancements accelerate, intellectual property protection becomes increasingly important. Policymakers should ensure that the legal framework is robust to protect innovation and incentivize research and development.
- **Sustainable Practices:** Industry 4.0 can have a significant impact on resource utilization and environmental sustainability. Policies should incentivize sustainable practices, such as energy-efficient technologies and circular economy principles.
- **Data Governance and Ownership:** With the proliferation of data in Industry 4.0, policymakers must establish clear rules regarding data ownership, access, and usage to ensure fairness and transparency.
- **International Collaboration:** Industry 4.0 is a global phenomenon, requiring international collaboration to address cross-border challenges, such as data flows and cybersecurity threats.
- **Infrastructure for Innovation Ecosystems:** Policymakers should invest in innovation ecosystems, such as technology parks and incubators, to promote research and development in emerging technologies. These ecosystems are essential for nurturing startups and fostering innovation.
- **Ethical Considerations:** As autonomous systems become more prevalent, policymakers should address ethical considerations related to AI and robotics. Ethical frameworks and guidelines can help navigate the challenges of AI ethics and responsible AI development.

In conclusion, policymakers play a pivotal role in shaping the response to the challenges and opportunities presented by Industry 4.0. By focusing on digital infrastructure, education, regulation, SME support, and other key areas, they can create an environment where Industry 4.0 technologies contribute positively to economic growth and sustainability. Dealing with the complex challenges presented by Industry 4.0 necessitates a comprehensive policy approach that aligns with the logical progression of this transformative technological era. The foundation of these policy implications is rooted in the understanding that Industry 4.0 fundamentally alters the dynamics of industries, economies, and societies. The interconnected nature of these implications underscores the need for a holistic strategy that encompasses various dimensions. Investment in digital infrastructure and education is a logical starting point. Without a robust digital infrastructure, seamless connectivity and data exchange cannot occur, hindering the full realization of Industry 4.0's potential. Simultaneously, the emphasis on education is crucial, as it is the cornerstone of equipping the workforce with the necessary skills for the digital age. This foundational support sets the stage for the subsequent policies.

Updated regulations and standards are essential to address the challenges presented by Industry 4.0. The evidence lies in the fact that this technological shift introduces new complexities related to data privacy and security. The logical course of action is to adapt regulations to this evolving landscape. Moreover, harmonizing international standards is imperative. It facilitates interoperability, a logical requirement for seamless global business operations, and data exchange. Support for Small and Medium Enterprises (SMEs) logically follows. These businesses face unique challenges in adapting to Industry 4.0 due to higher costs and complexities associated with adopting new technologies. Policymakers should provide incentives to level the playing field and promote SME competitiveness. The synergy between SME support and regulations further emphasizes the interconnectedness of these policies. Reskilling and workforce adaptation emerge as the logical response to the shifting job landscape in Industry 4.0. As technology disrupts traditional roles, it is logical that the workforce should be prepared to adapt. Continuous learning and adaptability are essential for addressing this change. This policy aligns with the broader strategy, acknowledging that a well-prepared workforce is vital for the success of Industry 4.0.

Stronger intellectual property protection is an evident need in Industry 4.0, where innovation and R&D thrive. The logical step is to establish robust legal frameworks to safeguard intellectual property rights, incentivizing research and development. This policy further complements the overarching strategy for fostering innovation and competitiveness. The call for sustainable practices aligns with the evident environmental impact of Industry 4.0. These technologies have the potential to reduce resource waste and promote sustainability. Policymakers should logically incentivize sustainable practices, aligning with global environmental goals. This policy integrates with the overarching approach, acknowledging the importance of environmental responsibility. Clear rules regarding data governance and ownership logically emerge from the proliferation of data in the Industry 4.0 landscape. The need for these rules is grounded in ensuring fairness, transparency, and responsible data handling. This policy forms an essential part of the comprehensive strategy for managing the vast amounts of data generated in the Industry 4.0 era.

International collaboration is a logical extension of the policy framework, given the global nature of Industry 4.0. As this transformation spans national borders, cooperative efforts are necessary to address cross-border issues like data flows and cybersecurity. This policy aligns with the overarching approach, recognizing the need for transnational cooperation. Investment in innovation ecosystems logically follows, as it fosters research and development in emerging

technologies. The historical success of innovation hubs and technology parks in nurturing startups and driving innovation reinforces the importance of these ecosystems. This policy integrates with the broader strategy, emphasizing the significance of technological advancement and competitiveness. The recommendation to address ethical considerations concerning AI and robotics is grounded in the increasing prevalence of these technologies. Logic dictates that as autonomous systems become more integrated into daily life and business, ethical guidelines and frameworks are crucial to navigate the potential moral and societal challenges. This policy fits seamlessly into the overall strategy, recognizing the importance of ethics and responsible technology adoption.

In summary, the interconnection of these policy implications forms a comprehensive and logical strategy for addressing the multifaceted challenges posed by Industry 4.0. This integrated approach recognizes the complex nature of this technological transformation and emphasizes the importance of aligning policies across various dimensions to effectively navigate the Industry 4.0 landscape and the policy implications drawn from the challenges of Industry 4.0 are highly relevant in the current environment. They provide a strategic roadmap for governments and policymakers to navigate the complexities of this technological era. These policies are not mere theoretical suggestions but represent actionable steps to harness the benefits and mitigate the risks associated with Industry 4.0. By addressing digital infrastructure, education, regulations, SME support, workforce adaptation, intellectual property, sustainability, data governance, international collaboration, innovation ecosystems, and ethical considerations, these implications offer practical solutions to real-world challenges. They align with the demands of the digital age, ensuring that nations can compete in the global arena and usher in a sustainable and responsible era of technological innovation.

Thus, the research posits an expansive framework offering recommendations concerning employment conditions within the context of the Industry 4.0 revolution and their interplay with the labor market. This comprehensive framework encompasses suggestions of both organizational significance and those with the potential for national or international implementation. The primary aim of this endeavor is to make a substantive contribution to policy formulation and strategic planning, with a specific focus on equipping the workforce for future employment conditions, anticipating impending labor market shifts driven by technological advancements, and effectively adapting to evolving competitive dynamics wrought by the Industry 4.0 revolution. To pave the way for future national and international applicability, it is imperative to approach the subject matter through diverse case studies, allowing for comprehensive evaluation, continuous refinement of results, and cross-comparisons with existing literature. Moreover, this research concludes with a set of recommendations, thoughtfully tailored to reflect the initial responses of the study participants. Given their derivation from participant feedback collected within the study's framework and their unique pertinence to this research, these recommendations merit special emphasis. They are enumerated as follows:

- **Fostering Sustainable Growth:** It is imperative for organizations to vigilantly monitor technological advancements and continually recalibrate their business models to underpin sustainable economic growth and efficiency.
- **Enhancing Workforce Agility:** To promote societal contentment and bolster productivity, it is incumbent upon organizations to ensure their workforce possesses the agility to navigate evolving working conditions.
- **Evolving Human Resource Management:** The evolution of human resource units within organizations is essential to effectively navigate dynamic conditions and oversee the development and adaptability of the workforce.
- **Globalized Workforce Education:** In the context of preparing future employees, the formulation of regional, national, or global education policies may confer distinct advantages in ensuring a skilled and adaptable workforce.
- **Environmental Responsibility in Business Models:** Future business models must prioritize environmental sustainability, underscoring the need for eco-friendly practices and responsible resource management.
- **Strategic Technological Integration:** Organizations should strategically integrate emerging technologies into their business models to foster sustainable growth and competitive advantage.
- **Human Capital Investment:** The cultivation of human capital is paramount, necessitating investment in training, skill development, and continuous learning to align with Industry 4.0 demands.
- **Collaborative Industry Networks:** The establishment of collaborative networks and partnerships among organizations can facilitate knowledge-sharing and collective efforts to adopt sustainable business models.
- **Policy Support for Industry Transition:** Governments and regulatory bodies should enact policies that encourage and incentivize the transition toward Industry 4.0 and sustainable business practices.
- **Data-Driven Decision-Making:** Organizations should leverage data analytics and AI to inform decision-making, optimize resource allocation, and minimize environmental impact within their business models.
- **Reskilling and Upskilling Initiatives:** Initiating reskilling and upskilling programs for employees to acquire new competencies is crucial for both individual career growth and the adaptation of the workforce to changing industry requirements.
- **Stakeholder Engagement:** Organizations should engage with a broad spectrum of stakeholders, including employees, customers, suppliers, and communities, to align their business models with sustainable values and societal expectations.
- **Sustainable Supply Chains:** To ensure the environmental sustainability of business models, it is imperative to extend these considerations to supply chain management, reducing the carbon footprint and promoting responsible sourcing.
- **Circular Economy Principles:** Embracing the principles of a circular economy, wherein resources are reused, remanufactured, and recycled, can be instrumental in crafting sustainable business models.
- **Ethical AI and Automation:** Ethical considerations in the deployment of AI and automation technologies are vital, and businesses

should prioritize the development and adherence to ethical guidelines in their business strategies.

Nonetheless, as is common in the conduct of research, certain limitations have become evident during the execution of this study. Originally, the intent was to encompass participants from a diverse range of countries within the research sample. However, due to significant material and ethical constraints, coupled with the absence of external organizational support, the inclusion of participants was confined to specific countries. Concurrently, a notable observation surfaced during the course of this research, indicating varying attitudes and priorities toward Industry 4.0 among organizations across different countries. While some nations exhibited a cooperative stance and accorded significant importance to the concept of Industry 4.0, the converse was observed in other countries. It is noteworthy that the preponderance of study participants originated from Germany, recognized as the pioneering epicenter of the Industry 4.0 paradigm, with some contacted countries failing to provide any feedback. This phenomenon not only underscores the present research's inherent biases but also presents an intriguing avenue for future discussion and investigation.

Furthermore, a comprehensive juxtaposition of the extant literature and the empirically derived insights from theoretical research underscores a conspicuous pattern. Namely, the research participants appear to have either neglected specific facets, such as Regulation and Standardization, Intellectual Property Protection, Data Governance and Ownership, and Ethical Considerations, or attributed insufficient significance to these aspects. A meticulous examination of these limitations is expounded upon in greater detail within the confines of the discussion section, thus furnishing a comprehensive elucidation of the implications. In light of these discernible limitations, it is prudent to proffer a recommendation within the purview of this study. Policymakers and researchers alike are encouraged to consider and address this particular circumstance in their forthcoming investigations. This serves as a call to action, emphasizing the need for a more holistic and comprehensive examination of the aforementioned facets to ensure a well-rounded perspective on the intersection of Industry 4.0 and sustainable business models.

To discern a significant implication arising from this study and to underscore the extent to which Industry 4.0 technologies have advanced, it is instructive to provide the forthcoming example. In the process of proofreading and refining this work, we availed the assistance of AI, specifically the ChatGPT language model developed by OpenAI. This collaboration exemplifies the integration of AI-driven tools into contemporary business models. Leveraging such technology demonstrates the ever-expanding potential of AI in enhancing efficiency and accuracy within academic and professional contexts. This instance underscores the growing significance of AI-powered tools as valuable assets in the realm of scholarly and business endeavors, further corroborating the transformative role of AI in modern business models.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest to be declared in the research.

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