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UNIVERSITY OF VAASA

Anuruddika Swarnamali Bandara Wanninayake

**Digital Transformation towards Environmental
Sustainability Practices in Leading Biscuit
Manufacturing Firms in Sri Lanka**

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Author:	Anuruddika Swarnamali Bandara Wanninayake		
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ABSTRACT:

The intersection of digital transformation and environmental sustainability have become a more prominent source of interest within the context of modern management studies, although empirically, there is a lack of evidence concerning the topic, especially when it comes to the food manufacturing sector. This study fills that gap by discussing the effect of digital transformation on the practice of environmental sustainability in biscuit manufacturing companies in Sri Lanka.

The present study follows a case study research design and uses interpretive philosophy and an inductive approach to research, which is a qualitative research methodology. Six senior respondents were interviewed in depth using semi-structured interviews in two of the major Sri Lankan biscuit manufacturing firms. The thematic analysis was used to analyze interview data, and it involves systematic transcription, coding, classification and development of themes to come up with findings that respond to the central research question and objectives.

The results showed that digital transformation is significantly affecting the environmental sustainability practices in the sector. Enterprise Resource Planning systems, Internet of Things sensors, real time environmental monitoring platforms and data analytics solutions are now deeply integrated in both companies, and, in essence, environmental management has shifted to real time, continuous, evidence-based practice, as opposed to periodic and retrospective governance. The research also finds that digital transformation comes with its own environmental risks such as carbon footprint of digital infrastructure, electronic waste due to the obsolescence of hardware and data integrity risk in the environmental reporting. The two companies showed active risk reducing policies such as sustainable technology procurement policies, responsible management of hardware lifecycles, and independent verification of environmental performance data.

The study concludes that digital transformation, when a strategically planned part of environmental sustainability objectives and managed with proper environmental rigor, can act as a transformational and dynamic facilitator of meaningful and measurable environmental sustainability performance in biscuit manufacturing companies.

KEYWORDS: Digital Transformation, Environmental Sustainability, Biscuit Manufacturing, Internet of Things, Developing Economies

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Abbreviations

AI	Artificial Intelligence
APQO	Asia Pacific Quality Organization
BDA	Big Data Analytics
BSC	Balance Score Card
CDP	Carbon Disclosure Project
CEA	Central Environmental Authority
CSR	Corporate Social Responsibility
EBSCO	Elton B. Stephens Company
ERP	Enterprise Resource Planning
ESG	Environmentally Sustainable Goals
GHG	Green House Gas
GNI	Gross National Income
GPEA	Global Performance Excellence Award
GRI	Global Reporting Initiative
IIOT	Industrial Internet of Things
IoT	Internet of Things
IR	Integrated Reporting
ISO	International Standard Organization
IT	Information Technology
MES	Manufacturing Execution Systems
ML	Machine Learning
SASB	Sustainability Accounting and Standard Board
SDG	Sustainable Development Goals
SMEs	Small and Medium-sized Enterprises
SSCM	Sustainable Supply Chain Management
UN	United Nations

1 Introduction

1.1 Background for the Study

Current trends indicate companies that have embraced the use of technologies like Artificial Intelligence (AI), Blockchain, Big Data Analytics, Cloud Computing, and the Internet of Things (IoT) are becoming competitive due to the ability to increase resilience, innovation, and stay customer-oriented (Rane et al., 2024). These digital tools support sustainability initiatives, including paper reduction, energy efficiency, and circular economy models (Rane et al., 2024). Fonseka et al. (2022) states that the high rate of digitalization of the global economy is likely to result in sustainable development in 2030. Meanwhile, the present-day organizations face more complicated and unpredictable challenges linked to business and environmental aspects, which emphasize the necessity to combine economic, social, and environmental procedures in their strategies to ensure a competitive advantage (Sołoducho-Pelc & Sulich, 2020). Organizations are in turn re-considering their growth strategies by embracing emerging technologies (Fonseka et al., 2022). The authors also point out that digitalization is the way to achieve sustainable development, and businesses need to consider digital platforms in their strategic planning to keep pace with the changing world market (Fonseka et al., 2022).

The environmental dimension of sustainability has become one of the most important issues in the global manufacturing sphere. When considering a broader range of the environmental effects of industry, in the United States, the food manufacturing sector was revealed to be the worst performer and the cause of the greatest environmental impacts, such as 20% of the national greenhouse gas emissions and 12% of the water withdrawals (Sovacool et al., 2021). In this respect, according to Arditho et al. (2021), they further seek to understand the connection between environmental orientation and innovation performance, which helps to conceptualize the firm-level option of going green and emphasizes the importance of environmental strategy with strategic elements. In the context of biscuit manufacturing companies, in particular, these issues are of utmost concern because of the energy-consuming characteristics of the baking process, the amount

of packaging waste produced, and the reliance on agricultural raw materials that are more prone to variability in climate.

Digital transformation has also been known to be a powerful driver towards environmental sustainability in the manufacturing setting. It is also as deep on process optimization, with businesses increasingly rapidly resorting to AI to assist in taming operations by automating them, predictively maintaining, and deploying resources intelligently, thus lowering their environmental impact (Rane et al., 2024). Moreover, digital tools help to create higher transparency and traceability throughout the supply chain, which allows the firms to show that they adhere to the environmental standards and respond better to stakeholder expectations of accountability. Such features make digital transformation not just an efficient tool in the economy, but a strategic tool to drive the environmental pillar of sustainability.

Environmental sustainability and digitalization in companies have started to be considered separately. Nevertheless, the development of sustainability into digital transformation and information technology is still relatively underexplored (Mohamed Hashim et al., 2022). Furthermore, another issue that is highlighted by Lubaba et al. (2025) is that in the existing literature, there is no adequate qualitative information about the sustainability implementation at the firm level among the food manufacturing companies in developing countries. Thus, the gap in knowledge relevant to this study is the need to understand how digital transformation can facilitate the sustainability practices of major companies producing biscuits in Sri Lanka. The research is expected to measure the degree of the current digital transformation among these companies, review their current environmental sustainability practices, and understand the perceived advantages and threats of employing digital transformation to foster environmental sustainability.

Biscuit manufacturing firms in Sri Lanka fall under the broader food and beverage manufacturing industry. This sector is the largest contributor to the overall manufacturing

industry's impact on the national economy. According to the Central Bank Report of Sri Lanka (2021), as shown in Table 1.2 titled Gross National Income by Industrial Origin, the industrial sector makes the second-highest contribution to the country's Gross National Income (GNI), with the food and beverage sector leading within the manufacturing category. The two major biscuit producing companies in Sri Lanka are the subject of this study. These companies are known as leaders as they have received the APQO-GPEA (Global Performance Excellence Award) that is offered by the Asia Pacific Quality Organization. This is a national award of excellence in business that is given to those organizations that have won national quality awards every year. Being awarded the APQO-GPEA boosts the image of the company as a high-performing organization dedicated to fulfilling the expectations of the customers and other stakeholders (Asia Pacific Quality Organization Inc. [APQO], 2025).

1.2 Research Question and Objectives of the study

The major biscuit producing firms in Sri Lanka are players who play a significant role in the economy of the nation, but they face several challenges when they are undertaking the process of digital transformation and integrating environmentally sustainable operations. Even though sustainability practices are essential to long-term survival and digital transformation provides opportunities to achieve efficiency and growth, very little is known regarding how the two concepts can be combined. Although sustainability is unquestionably one of the phenomena that is growing rapidly, it is still an insufficiently discussed area of application for digital technology (George, et al., 2021). Therefore, the problem addressed by this research is the lack of knowledge regarding the integration of digital transformation for environmental sustainability practices in leading biscuit manufacturing companies in Sri Lanka.

This research paper explores how digital transformation and environmentally sustainable practices are related to each other. As emphasized by Guandalini (2022), the subsequent study should have a fresh approach to the subject since the disjointed thematic progression in current literature still poses a threat to a consistent insight into how digital

transformation assists sustainability goals. To fill this gap, the current study aims at contributing to existing scholarly research by determining the most crucial variables that affect consumer preference towards digital transformation initiatives, such as financial issues, readiness to adopt the digital transformation, environmental sustainability awareness, and the perceived advantages and risks of adopting digital solutions.

Even though the academic literature on the connection between digitalization and sustainability has been increasing over the past years, a lot of it is focused on the ecological aspect and remains underdeveloped in terms of theory. Thus, more research is necessary to gain a better insight into the role of digital transformation towards environmental sustainability practices. The proposed study will examine consumer preference towards digital transformation through the lens of environmental factors, which should provide valuable information that can guide policymakers, industry associations, and other stakeholders to enhance digitally sustainable ways of environmental sustainability.

This paper will aim to answer the following **question** accordingly:

How does digital transformation impact environmental sustainability practices in biscuit manufacturing firms?

The following main and sub-objectives will serve to answer the above question:

Main Objective:

To explore the impact of digital transformation on environmental sustainability practices in biscuit manufacturing firms.

Sub-Objectives:

1. To assess the current level of digital transformation among biscuit manufacturing firms, focusing on the adoption and integration of digital technologies.
2. To examine the environmental sustainability practices implemented by these firms.

3. To identify the perceived benefits and risks of digital transformation in enhancing environmental sustainability within the biscuit manufacturing sector.

1.3 Delimitations of the study

This study is delimited to two leading biscuit manufacturing firms in Sri Lanka that have received the APQO-GPEA award for business excellence. The research focuses exclusively on these firms because they are recognized as industry leaders and are more likely to have adopted advanced digital transformation and environmental sustainability practices. This study uses a qualitative case study approach, based on semi-structured interviews with a limited sample of key stakeholders, including senior managers, sustainability professionals, and IT professionals. This is based solely on the views and experiences of these respondents and not on the views and experiences of all employees in the organization or the external stakeholders, like customers or suppliers. Also, it carries out the study at a certain time and is not supposed to reflect the long-term alterations or the history. Lastly, the research does not aim to generalize its findings to the food and beverage industry as a whole or the manufacturing companies in Sri Lanka but proposes detailed insights into the samples.

1.4 Previous studies

Previous studies have also thoroughly analyzed digital transformation and sustainability as two distinct fields of study. Digital transformation research reflects the importance of emerging technologies like artificial intelligence, blockchain, and big data analytics and cloud computing in enhancing operational efficiency, innovation, and customer interaction (Rane et al., 2024). At the same time, sustainability research emphasizes the importance of focusing on the environmental, social, and economic dimensions of organizational strategies, and frameworks such as the Global Reporting Initiative (GRI) provide guidelines for measuring and optimizing sustainability performance (Mesquita et al., 2021).

More current research has started to examine the interconnection of digital transformation and sustainability, which is commonly called digital sustainability. As an example, Guandalini (2022) notes how integration of digital tools can facilitate beneficial changes in society and the environment, whereas George et al. (2020) focus on the importance of digital innovations in promoting the Sustainable Development Goals (SDGs) of the United Nations. Nonetheless, the application of terms like digital sustainability or digital transformation in sustainability-related contexts is underrepresented, even though there is a growing scholarly interest in this matter. A search in titles through EBSCO host using the word digital sustainability returned only 9 articles in the field of business/economics, of which only two articles were found to be relevant to the topic because sustainability and digital transformation are still a conceptually underdeveloped focus area (Guandalini, 2022). The existing gap increases its relevance in carrying out the investigation on the practical implementation of these concepts.

Research on digital transformation in the Sri Lankan context has been mainly centered on adoption of e-commerce and business performance among small and medium enterprises (Fonseka et al., 2022), and sustainability research has mainly involved the environmental management and corporate social responsibility in any sector. However, a gap in empirical literature that investigates the direct linkage of digital transformation with fostering sustainability practices within the food and beverage manufacturing sector, especially among the top firms in the biscuit manufacturing sector, still exists. To effectively promote the use of digital technology as a sustainable practice, there is an urgent need to devise specific strategies, support systems and policies that take into consideration the preferences and practices of Company 01 and Company 02. This study could help in achieving both the industrial growth and the overall sustainable development of Sri Lanka by determining the factors, which affect these choices.

1.5 Structure of the thesis

In this thesis, there are five major chapters. Chapter One introduces the study, providing the background, research questions and objectives, delimitations, and previous studies prior to giving the overall structure. Chapter Two contains the literature review, which concentrates on digital transformation, sustainability, and digital sustainability, sustainability practices by biscuit manufacturing firms, and the correlation between the two concepts. Chapter Three outlines the methodology of the research that consists of a research approach, method, and design, data collection, sampling strategy, data analysis, and ethical issues. Chapter Four summarizes and discusses empirical data, specifically the level of digital transformation that currently exists, the environmental sustainability practices that the firms currently have in place, and the perceived benefits and threats of digital transformation for environmental sustainability. Lastly, Chapter Five closes the thesis by summarizing the main findings, the theoretical contributions and managerial implications, and limitations of the study, as well as recommendation of future research. The thesis is preceded by references and appendices, which contain supporting material, e.g. the interview guide and other relevant documents.

2 Literature Review

2.1 Introduction

The chapter is a review of academic literature on the topic of digital transformation, sustainability practices, and its connections with manufacturing industries, specifically on the topic of the food and biscuit manufacturing industry. It also dwells upon the applicability of these notions in the context of developing countries and Sri Lanka in particular. The chapter ends with a key theoretical perspective which justifies the current study.

2.2 Digital Transformation

2.2.1 Concept and Evolution of Digital Transformation

To prove the substantiation of the theoretical base, this study is based on the major concepts of digitalization, digital transformation, sustainability, and digital sustainability, which helps to comprehend the changing interaction of technology and sustainable business operations. These guiding principles give the correct context to study the ways in which manufacturing organizations can operate in the sophisticated environment of technological innovation and at the same time seek environmental sustainability goals. However, there is still debate on the exact meaning of these terms. Guandalini (2022) explains that defining digitalization and related terms such as digital technology and digital transformation is complicated. There is ongoing debate between academics and practitioners about the boundaries of these concepts. Brenner and Hartl (2021) distinguish between digitization, digitalization, and digital transformation, describing them as related but separate ideas. At the same time, Mergel et al. (2019) note that these terms are often used interchangeably in the literature, which creates confusion and weakens conceptual clarity.

Digitization is typically perceived as the transformation of the analog information into the digital format and automation of the existing processes (Brenner and Hartl, 2021). It increases efficiency and does not basically transform business models or business

structure. In the same manner, Loebbecke and Picot (2015) mention that companies are primarily enhancing existing processes and integrating improved product and service quality with the aid of digitization and big data analytics. Berger et al. (2021) link digitization to increased innovation and entrepreneurship by improving access and participation. However, Hilali et al. (2020) argue that digitization is only a first step and should not be seen as the final goal, but rather as a foundation for digital transformation.

Digitalization goes beyond efficiency improvements. According to Gartner (2021), it refers to the use of digital technologies to create new business opportunities and generate value. Digital transformation is a more profound and radical change. According to Gong and Ribiere (2025), it is a change in an organization that recreates business models with the use of digital technologies. In the same manner, Hanelt et al. (2021) understand digital transformation as the change of the organization under the impact of the widespread use of digital technologies. Brenner and Hartle (2021) also add that digital transformation can result in entirely new business models founded on new value creation and capture logic. This reflects an obvious way of development: the improvement of the processes (digitization) to the redesign of the whole business model (digital transformation).

The emerging technologies that lead to digital transformation are artificial intelligence, big data, cloud computing, and the Internet of Things that develop at a high speed (Mohamed Hashim et al., 2022). These technologies are constantly transforming the way the firms operate and compete. Nevertheless, the need to incorporate sustainability into the digital transformation is not achieved without intentional efforts. Mohamed Hashim et al. (2022) emphasize that sustainable digital transformation is associated with virtualization using cloud computers, connectivity technologies integration, e-waste minimization, energy efficiency, and novel architectural designs. They also emphasize the centrality of explicit key performance indicators to indicate the extent to which digital transformation can be made sustainable. It means that digitalization does not necessarily translate into sustainability but should be a controlled process.

Guandalini (2022) introduces the concept of “digital sustainability,” reflecting the growing link between digitalization and sustainability. The term combines the strategic goals of digital transformation and sustainability to promote positive environmental and social outcomes. Similarly, George et al. (2021) define digital sustainability as organizational activities that use digital technologies to support the Sustainable Development Goals. They argue that digital technologies increase scalability and remove geographic limitations, allowing organizations to create wider impact.

Nevertheless, achieving sustainable competitive advantage through digital transformation remains challenging. Mohamed Hashim et al. (2022) explain that although sustainable digital transformation aims to create long-term competitive advantages, the fast-changing digital environment makes it difficult to maintain them. Therefore, firms must continuously adapt and innovate.

These ideas are very applicable in the setting of manufacturing specifically in the Sri Lanka biscuit manufacturing industry. There is growing pressure on manufacturing companies to become efficient and minimize their environmental impact and to satisfy the demands of their stakeholders. When digital transformation is aligned to sustainability, business organizations can generate value beyond financial performance like environmental and social benefits. Thus, to study the way digital technologies can help sustainability in manufacturing, it would be critical to understand the development of digital transformation and its relationship with sustainability.

2.2.2 Digital Technologies Enabling Transformation

The process of manufacturing digital transformation is based on a system of connected ecosystems of advanced technologies which essentially transforms the process of production and the capabilities of the organization. All these technologies are synergistic in their work towards improving efficiency, sustainability, and competitive advantage. The technologies most frequently utilized in digital sustainability efforts encompass distributed ledger technologies (blockchain), artificial intelligence and machine learning

(AI/ML), big data analytics, mobile technologies and applications, sensors, various IoT devices, and other telemetry tools such as satellites and drones (George et al., 2021).

The Internet of Things (IoT) describes a networked environment in which physical objects are equipped with electronic sensors, actuators, and other digital components that enable them to connect and communicate with each other (Zhong et al., 2017). Artificial Intelligence (AI) refers to the scientific and engineering discipline that is devoted to the development of intelligent machines, especially computer-based systems that can fulfill tasks traditionally resulting in the use of human intelligence (Cioffi et al., 2020). According to Cioffi et al. (2020), the scope of artificial intelligence has grown considerably with the development of machine learning facilitated systems that have significant consequences on business, government, and society, and affect the sustainability trends in the world at large. According to Awan et al. (2021), big data analytics (BDA) are those datasets and methods of their analysis that are so large and complex that they require special technologies to store, manage, analyze, and visualize them. Cloud computing is an IT service model in which hardware and software resources are delivered on demand over a network, allowing users to access these services independently of their device or location (Marston et al., 2011). Edge computing is a term used to describe the technologies that make data processing and computation occur at the edge of the network, as opposed to the complete use of centralized cloud systems (Shi et al., 2016). Blockchain technology enables data collection, storage and administration, which allows managing important data about the products and supply chain safely (Saberri et al., 2019). The Manufacturing Execution Systems (MES) offer low-cost and quicker implementation time real-time visibility of correct high velocity production performance information in comparison to Enterprise Resource Planning (ERP) initiatives (Saenz de Ugarte et al., 2009). Along with the development of computing technologies, MES has become stronger and more integrated software applications. Simultaneously, ERP systems have acquired a leading market niche with an estimated 80 percent of Fortune 500 companies using ERP solutions to conduct their business and more small and medium-sized enterprises (SMEs) embracing the ERP solutions (Saenz de Ugarte et al., 2009).

George et al. (2021) state that technology-assisted citizen science, drones, the Internet of Things (IoT), and satellites are some of the important technologies that aid in filling knowledge gaps, blind spots, and enhance the quality and scope of information with which decision-makers can assess the risks of running a business and market failures at the expense of economic, social, and ecological. Manufacturing companies can prioritize the adoption of smart manufacturing technologies based on the specific needs and objectives they aim to address (Frank et al., 2019).

2.2.3 Digital Transformation in Manufacturing

Industry 4.0 is another phase of industrial transformation where physical, digital, and virtual systems are interconnected with the help of cyber-physical technologies and the Internet of Things (IoT), but cognition an intelligent ability to acquire, process, and apply knowledge is also considered a significant part of it (Winter, 2022). Smart manufacturing, in its turn, is a highly developed mode of production, which has been improved in terms of performance by intelligently connecting processes and resources on cyber, physical, as well as human levels, and by intersecting with other spheres of the enterprise value chain to design, manufacture, and offer products and services (Winter, 2022).

Effective digital transformation initiatives begin with a set of well-articulated business objectives rather than with the aim of adopting new technologies as a priority and they aim to interconnect core systems using current integration solutions rather than wholesale, radical alterations at once (Peřkala, 2025). In the context of manufacturing, smart manufacturing is no longer an approach that focuses on enhancing the productivity of manufacturing plants, but an approach that focuses on value creation to the whole value chain (E2E) including plants (Jin, n.d.). Going digital with your manufacturing process is not only the way to remain on par with the recent trends, but it is a serious effort to transform your business to be more sustainable and provide workers with better safety and productivity, as well as the quality of their products (Shoplogix, 2024).

Microsoft (2025) states that several challenges related to the 4.0 transition industry are present. It may be complicated and time-consuming to incorporate the existing assets

into the digital transformation process. The other issue is that the skills gap between new hires in such areas as data science, AI, and cybersecurity is likely to be high, and with the emerging loss of the experienced employees by retirement.

2.2.4 Digital Transformation in Developing Economies

Although digital transformation offers significant opportunities in the development of organizations, emerging economies face unique obstacles that set them apart in terms of the paths of transformation they follow in developed countries. Ha and Chuah (2023) indicate that the transition is associated with several challenges in developing countries, such as the digital divide arising due to age, IT literacy, income, and skills differences, and the existence of the internet, with differences occurring between and within countries; with different levels of human capital development; with issues of data privacy and the security of online systems; with taxation and jurisdiction-related issues; and other constraints, including limited resources, weak financial and online payment systems, insufficient protection of intellectual property, infrastructure shortages, regulation, issues of consumer protection, and constraints of sustainability. Amid these issues, the developing economies indicate high innovation potential via context-specific directions.

In the Sri Lankan context, the analysis determined that there are 23 reasons that led to the failure of digital transformation in the Sri Lankan government with the study identifying them as falling under five categories: organization weaknesses, implementing agency constraints, cultural constraints, ineffective leadership, and macro level political instability (Syed et al., 2023). However, the level of e-commerce technology utilization in Sri Lanka is way lower than the other developing countries in the region because of lack of awareness of the benefits of e-commerce strategy (Fonseka et al., 2022).

2.3 Sustainability and Sustainable Development

2.3.1 Evolution of Sustainability Concept

Experts have always been involved in the definition of sustainability. Early definitions in 1972 emphasized limitations on ecological systems, performance of functions like

absorption and recycling of waste of anthropogenic activities and the attendant issues of enhancing social, educational, health, and employment (Hajian & Kashani, 2021). As noted by Stuermer et al. (2017) mention, the UN Brundtland Commission (1987) provided the most widely recognized definition of sustainability: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In 2019, sustainability was further conceptualized as meeting the demands of the present and the future generations based on the right conditions of both human and natural capital, as well as economic capital to support the welfare of humanity (Hajian & Kashani, 2021). The authors further argue that the concept has developed in recent years to include considerable economic and social complexity, with different nations demonstrating that high rates of financial growth have brought about severe issues of sustainability, such as social, economic, and environmental sustainability.

Building on these foundations the United Nations adopted universal 17 Sustainable Development Goals (SDGs) in September 2015 to tackle the most critical aspects of humanity such as poverty, inequality, climate change, peace, prosperity, and environmental sustainability (United Nations, 2015). They further state that the SDGs are a goal to be met by 2030 and act as a plan on how to create a more inclusive, equitable, and sustainable world. However, Ordonez-Ponce (2023) mentions that despite some notable improvement since their introduction, some social goals (SDGs 2, 3, 7, and 11) and environmental ones (SDGs 6 and 14) have increased, but it is not a guarantee of actual sustainability growth and overall success. The author even goes further to state that this is a critical consideration as we further develop the sustainability agenda and start gearing up towards a new framework that would be in place to replace the SDGs once they expire in the next few years.

2.3.2 Sustainability in Manufacturing

Food manufacturing contributes more than 25% of greenhouse gas emissions with a substantial portion of water extraction and pollution (Ahmad & Wong, 2019). The authors emphasize that it is a common trend that sustainable development in general and

sustainable manufacturing specifically are becoming a requirement to address the demands of the rapidly increasing population, environmental pollution and social injustices.

Circularity of a business model and supply chain is given as a precondition towards sustainable manufacturing, which is needed to enhance economic and environmental performance of industrialized countries and developing countries, and the author also references the circular economy as one of the most important aspects of sustainable development (Geissdoerfer et al., 2017). Furthermore, the authors describe the circular economy as a regenerative system whereby the material and energy input, waste, and energy leakage is reduced by slowing down, closing, and shortening material and energy loops. This would be possible with long-term design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling. They also define sustainability as the harmonious combination of economic performance, social inclusiveness, and environmental integrity, in the favor of the present and future generations.

Nevertheless, most manufacturers are yet to transition to sustainable production and manufacturing and even struggle with measuring their sustainability performance (Ahmad & Wong, 2019). These gaps directly guide the investigation in this study on how the digital transformation technologies can facilitate a more efficient measurement and application of the principles of the circular economy and waste management strategies in the biscuit manufacturing companies to not only deal with the measurement issues, but also to respond to the practical sustainability needs.

2.3.3 Sustainability Reporting and Frameworks

The frameworks of sustainability reporting are seen as the primary avenues through which businesses report and conduct their triple bottom line performance. Global Reporting Initiative (GRI) is the most popular reporting standard employed globally to this day (KPMG, 2022). According to Bais et al., (2024) GRI is the most spread and all-encompassing even though other tools are equally getting attention i.e. the Carbon Disclosure Project (CDP), the Integrated Reporting (IR) framework and the Sustainability Accounting

and Standard Board (SASB). At the operational level, ISO 14001 higher adoption is correlated with decreased energy intensity, lower rate of Green House Gas (GSG) emissions and high consumption of renewable energy in international manufacturing firms (Ces-tau-Oyhantçabal & Arocena, 2025).

Corporate Social Responsibility (CSR) issues related to the food industry, include the aspect of sustainable development in both social and business spheres, the problems of health and safety of the population (He et al., 2022). The authors also imply that bibliometric research is needed to produce the degree of satisfaction of social responsibility of food enterprises, protection of the safety of food and consumer rights, and the high-quality and sustainable development of the food enterprise. Very importantly, Bindeeba et al., (2025) brings a meta-analysis of Digital Transformation and sustainability and generalizes the three pillars of the Environmentally Sustainable Goals (ESG) into one index, eliminating domain-specific tendencies.

For performance measurement, Damtoft et al. (2025) recommend that integrated tools be considered, including the Sustainability Balanced Scorecard instead of single indicators. Most recently, the Balance Score Card (BSC) has been adapted by practitioners to facilitate sustainability strategy implementation (Tawse and Tabesh, 2023). The combination of these frameworks comprises the evaluative base of determining sustainability practices in Sri Lankan based manufacturing firms producing biscuits.

2.4 Digital Sustainability: The Convergence

2.4.1 Conceptualizing Digital Sustainability

Digital sustainability is a relatively new and fast-growing concept existing at the intersection of digital transformation and sustainable development. The conceptual work by Kotlarsky et al. (2023) in the Journal of the Association of Information Systems defines the notion of digital sustainability as the creation and implementation of digital resources and artifacts to enhance the environment, society, and economic well-being. This definition encompasses the application of digital technologies to meet the

sustainability goals and the fact that digital technologies should be sustainable. The authors also mention that the concept of digital sustainability is becoming an increasingly common term used by practitioners to define the relationship between digital technologies and sustainability-related issues.

Likewise, a complementary definition given by George et al. (2021) refers to digital sustainability as organizational operations that further the Sustainable Development Goals by the innovative application of technologies that create, transmit, or source digital data, therefore, focusing on strategic intent and intended action. As much as digitalization is highly perceived to offer enormous opportunities in the pursuit of sustainability, Gandolini (2022) warns that when this is not managed in a proper manner, unintended, or underestimated, it can also cause disruptive effects that affect the sustainability outcomes in a negative manner.

In the research, the author evaluates the digital transformation projects in the context of Sri Lankan biscuit production, more specifically on how it can produce meaningful and quantifiable sustainability impacts in the environmental aspects.

2.4.2 How Digital Technologies Enable Environmental Sustainability

Digital technologies are multi-dimensional sustainability enablers, generating quantifiable benefits in environmental aspects. According to Lanfranchi et al. (2025), IoT enables an easy integration of renewable sources of energy and energy optimization; hence, it helps to lower carbon emissions and achieve energy efficiency. In addition to this, using digital technologies like AI-based analytics and IoT sensors, waste management systems can become more eco-effective and control environmental impacts, as well as facilitate selective monitoring and certification behaviors (Seyyedi et al., 2024). The most common aspect of blockchain technology application in rising supply chain transparency is at the supply chain level. Moreover, it is possible to enhance the efficiency of a supply chain with the help of IoT and big data analytics (Rusch et al., 2023). The results are directly applicable to the food and biscuit manufacturing supply chains where the ingredient provenance and cold chain efficiency are essential sustainability issues.

Most importantly, researchers warn that these advantages depend on the organizational willingness and alignment to a strategy, introducing digital tools without integrating them into a consistent sustainability plan has fractured and sub-optimal results. In the current research, these understandings form the analytical prism under which the effects of digital transformation on the environmental sustainability is analyzed among the Sri Lankan biscuit manufacturing companies.

2.5 Sustainability Practices in Food and Beverage Manufacturing

2.5.1 Overview of Food and Beverage Industry Sustainability Challenges

The food and beverage industry experiences compound effects of sustainability pressures on the use of resources, waste, and supply chain management. Corigliano & Algieri (2024) identify the fact that energy, water and waste are inseparable processes in food production highlights the necessity to minimize loss and waste during the supply chain, increase energy efficiency in food processing, and reduce resource use. The increased global interest in solving the sustainability dilemma of decreasing material consumption and waste packaging, by creating reusable packaging structures (Coelho et al., 2020). These pressures are further added by complexity in the supply chain with the fact that corporate scope 3 emission reporting is not a common reporting practice by most firms and non-reporting firms, as confirmed by Hettler et al. (2024), might not help them see the bigger picture of their total carbon footprint and make effective decisions when it comes to their decarbonization efforts.

Researching that the barriers to Green Manufacturing in an emerging economy situation comparable to Sri Lanka and discovering that the inconvenience in adapting the eco-friendly design concepts, absence of efficient recycling plants and expensive initial investment and inaccessibility of the funds are the most significant aspects that put pressure on the adoption of GM in food and beverage industry, Lubaba et al. (2025) have studied.

2.5.2 Best Practices in Food Manufacturing Sustainability

The major food producers run sustainability down to certification systems and sector standards, as well as production innovation, globally recognized. Such established concepts/practices with the aim of achieving sustainability, other than Circular Economy, include sustainable supply chain management (SSCM), eco design, design for sustainability and sustainability assessment (e.g., life cycle assessment [LCA], ISO, 2006; or social LCA) (Rusch et al., 2023).

However, Adams et al. (2023) critically note that although technologies and the emergence of Industry 4.0 are also becoming a factor that determines the trend of the new research areas, researchers are exploring the possibility of leveraging the blockchain technologies to facilitate and empower sustainable supply chains, and blockchain adoption in the field of the food industry is still in its exploration. These are the benchmarks used in this research to evaluate the sustainability of the manufacturing practices of Sri Lankan manufactures of biscuits.

2.6 Digital Transformation for Sustainability in Manufacturing

2.6.1 Empirical Evidence of Digital-Sustainability Integration

The sustainability implications of the digital transformation review literature area are very wide, though it may vary based on the specific case. Bindeeba et al., (2025) confirm the aforementioned as, according to a meta-analysis that combines 59 studies (consisting of 835.000 firm-year observations), digital transformation improves ESG scores, though the largest difference is received in business-process digitization, then data infrastructure upgrades.

However, mixed and negative results are also reported in the literature. According to Bindeeba et al. (2025), Tan et al.'s bibliometric mapping confirms that the most prolific period of Digital Transformation integrated with Environmental, Social, and Governance principles (DT-ESG) research is 2023-2025 but indicates that theoretical integration still

is behind and enumeration. Jin and Wu (2024) hold that under an institutional context; the informal system has a positive moderating influence with the connection between digital transformation and ESG performance. That is, informal institutions and digital transformation have synergy to increase corporate ESG results. The observation can be applied especially to the manufacturing situation of Sri Lanka where the institutional sustainability module is still at its initial development phase.

2.6.2 Digital Technologies Applied to Sustainability in Manufacturing

There are several digital technologies that have taken the place of one of the primary sustainability enablers in the manufacturing process. In various studies, digital applications of Digital Transformation, which can include AI-based HR analytics, digital communication platforms, and online training, have enhanced workplace safety and engagement (Bindeeba et al., 2025).

AI and big-data analytics enhance the forecasting of the environment, allow constant observation of emissions, and enhance predictive risk management (Bindeeba et al., 2025). Martínez-Peláez et al. (2023) state, with technologies such as data analytics, the Internet of Things (IoT), and cloud computing, micro-small and medium-sized enterprises (MSMEs) will be able to optimize energy use and waste management and make better-informed choices to facilitate sustainable manufacturing processes. They further emphasize that not only do these technologies prove beneficial to the environment, but they also efficiently increase the operational effectiveness and cost efficiency of MSMEs. The tools, including blockchain and cloud-based collaboration solutions, allow companies to work together in the field of sustainability, optimize the use of resources, and attempt to align their business objectives based on sustainability (Elnadi et al., 2026). Combined, these technologies will constitute a stacked digital architecture of sustainability, particularly relevant to the setting of ingredient traceability, minimal energy consumption, and controlled packaging life cycle, being functional requirements simultaneously in biscuit production.

2.6.3 Benefits of Digital Transformation for Sustainability

Digital transformation has numerous strategic and multi-dimensional positive effects on sustainability. Bindeeba et al. (2025) mentioned that the case studies conducted in Uganda demonstrate that these digital tools can bring significant changes in eco-efficiency in SMEs, which is achieved in cooperation with credit access and management training. They further argue that these changes can be framed around SDGs objectives of decent work (SDG 8), innovation (SDG 9), responsible consumption (SDG 12) and climate action (SDG 13), to ensure that firms are able to match internal reforms to the demands. Jin and Wu (2024) state that digital transformation enhances the environmental governance capacity of the state-owned enterprises. They further emphasize that it can mitigate the high-input, high-consumption, and high-pollution nature of manufacturing companies by reducing the costs of green innovation, improving the performance of green innovation, facilitating the production system to be circular and green, and, eventually, decrease carbon emissions.

Evidence-based decision-making enhances strategic investment in sustainability that helps firms to realize high-impact intervention points in the value chain. The modern business environment is characterized by the key to sustainability via digital transformation. With the idea of being sustainable, micro-, small-, and medium-sized enterprises (MSMEs) can become competitive, which would attract customers and investors to promote the latter (Martínez-Peláez et al., 2023). Importantly, the first-mover advantages of digital transformation are also available: by incorporating digital sustainability functions before others, a firm can establish itself to take premium market segments, draw investment with an ESG focus, and influence the regulatory landscape, which all have direct strategic implications to the core business of leading biscuit manufacturers in Sri Lanka, which need to distinguish themselves within the domestic and foreign marketplace.

2.6.4 Risks and Challenges

Digital transformation to sustainability has significant risks and implementation issues despite its great potential. One of the challenges facing most companies is their ability to utilize the opportunities presented by the digital economy to improve the sustainable development of a company and at the same time deal with challenges that can hinder progress (Raihan, 2024). The technological infrastructure required for digital transformation, such as reliable internet connectivity, strong cybersecurity systems, and sufficient digital skills, constitutes essential structural conditions that are not uniformly available across all production sites or supply chain partners. Moreover, the concepts of cybersecurity and information privacy have become significant ESG topics, as have other more general challenges, such as the growth of electronic waste, the rise in energy use and carbon footprint, the digital divide, occupational security, the growth of monopolies, and risks to data protection (Raihan, 2024). Like any significant organizational change, digital initiatives can also face inertia and workers showing resistance to change (Ellström et al., 2022). In addition, the digital divide will have the effect of widening the sustainability gap between technologically advantaged and technologically backward companies, especially in developing economies where the adoption of infrastructure disparities can result in the sustainability benefits of large manufacturers but not smaller suppliers. All these issues point to the fact that the process of transition to digital sustainability needs to be carefully managed instead of presuming that it is going to happen automatically as a part of technological adoption.

2.7 Contextual Considerations

2.7.1 Digital Transformation in Sri Lankan Context

The digital transformation of Sri Lanka is developing both in an opportunity environment and a structural constraint environment. The domestic IT services sector in Sri Lanka is also recording signs of consistent growth with 17 percent of the yearly growth in the sector as reported by World Bank (2025) due to the known reputation of the country in software development and outsourcing. The industry has over 500 firms, it generates

about USD 1.3 billion in yearly income, and it has over 140,000 individuals in the workforce. The strategic focus of the Digital Economy Strategy 5.0 by the Sri Lankan Government are: i) developing digital industry, by expanding opportunities to established IT companies as well as new digital startups; ii) enabling transparent and efficient government, by digitalizing government services and creating new digital institutions; iii) expanding the digital economy, through encouraging widespread adoption of digital payments, with digital literacy and skilling; and iv) enhancing the development of strategic industries by digitalizing them (World Bank, 2025).

Nonetheless, the World Bank (2025) says that, even though the IT services sector in Sri Lanka has been acting as one of the strong pillars in the economy, more investment, development of skills, and access to world markets will be needed to ensure that growth and creation of employment continue to rise. These are the conditions that directly spell out the boundary conditions within which the integration of digital sustainability could be executed among the biscuit manufacturers of Sri Lanka.

2.7.2 Sustainability in Sri Lankan Manufacturing

The governance of environmental sustainability in Sri Lanka is founded on the National Environmental Act No.47 of 1980, and the Central Environmental Authority (CEA) implements Environmental Protection Licenses and revised emission standards to the prescribed industries (Central Environmental Authority, 2022). Nonetheless, voluntary sustainability reporting is still in its infancy: even according to the Global Reporting Initiative (2023) records only 92 Sri Lankan companies have sustainability reports as of 2023, and Thiranagama and Wahala (2024) report that only 23% of registered manufacturers publicly report environmental performance. Lubaba et al. (2025) affirm that the inability to implement environmentally friendly designing idea, the inexistence of effective recycling processes, high costs of initial investment and inability to provide financial support are the most significant obstacles to the adoption of green production in the emerging economies food and beverage companies - contextual factors, which directly determine the sustainability practices studied in the research.

2.7.3 The Food and Beverage Sector in Sri Lanka

The food and beverage industry in Sri Lanka is a key industry that has been strategically placed thus the major industry players are now more export-oriented and focus on international qualifications.

The Global Performance Excellence Award (GPEA) of the Asia Pacific Quality Organization in the Colombo secretariat is the oldest international award of overall organizational performance and business excellence in the region (Asia Pacific Quality Organization [APQO], 2026). Sri Lanka builder of flagship brand Munchee, Ceylon Biscuits Limited (CBL) declares its outstanding success in receiving the much-coveted BRCGS AA+ certification yet again and CBL has scooped the much-desired Global Performance Excellence Award (GPEA) in the status of a World Class (Ceylon Biscuits Limited [CBL], 2024).

This analytical and competitive environment forms the definite context of the analysis of digital sustainability integration of award-winning Sri Lankan companies in the manufacturing of biscuits in this research.

3 Research Methodology

3.1 Research Design and Philosophy

This qualitative research paper examines how digital transformation can facilitate environmentally sustainable practices among the major biscuit producers in Sri Lanka and uses two large corporations as examples to delve into the subject. Research design is a key component of any academic research because it identifies the general approach and direction in which the researcher gathers, analyses and interprets data. To achieve methodological consistency, this research will be based on the Research Onion model created by Saunders, Lewis and Thornhill (2007) which offers a layered and organized method of developing research starting with philosophical assumptions and ending with practical data collection choices.

Interpretive philosophy is followed in this study at the philosophical level. The reason is that the main phenomena that will be studied are not objective, measurable realities, but rather influenced by the perceptions, experiences, and values of individuals and organizations in question. Interpretivism recognizes that reality is socially constructed and that its explanation involves getting deeply involved in the subjective meanings that members of the group give to their experiences. This philosophical position thus fits in the objective of the study, which is to understand industry practitioners' perspective and experience on the intersection of technology and sustainability in their respective organizational settings.

In line with this interpretation position, the research adopts an inductive method of reasoning. The researcher goes into the field with open-ended questions and does not have a predetermined hypothesis to be tested but permits theories and patterns to develop out of the data as they arise. This can be especially useful in a setting like the biscuit manufacturing industry of Sri Lanka, where there is a lack of previous research on this connection between digital transformation and sustainable practices, and thus, theory generation is more suitable than theory testing.

Since the study is focused on gaining insightful understanding of the real-life organizational experiences in detail and in their natural contexts, a case study approach is embraced. According to Greenhalgh (2025), case study research is a process of investigation and exploration of real-life phenomena in a detailed and contextual form, which aims to grasp the how and why events happening using a set of sources of qualitative data. This methodology is particularly suitable to the current study because it gives the researcher an opportunity to understand the intricacies of individual organizations' digital and sustainability experience, both in terms of decision-making within the organization, external pressure, and situational forces that define their practices. The study is also able to compare the cases to some extent as it focuses on two organizations and thus adds to the overall findings.

It is exploratory in nature, trying to produce new insights on the relationship between digital transformation and sustainability instead of validating the existing theories. The study had a cross-sectional time horizon as the data was collected at one point in time. An online interview was performed through platforms like Microsoft Teams or Zoom, which allowed participants to participate in the interview through their organizations of work without geographical and logistical constraints. As the research is based on both primary interview materials and secondary documents, the multi-method approach to data collection is chosen, enhancing the overall validity and richness of the results.

3.2 Sampling and Data Collection

Appropriate selection of participants and data collection techniques will play a vital role in ensuring the research can provide meaningful, relevant and valid findings. The sample population will include the professionals of two of the top biscuit production companies in Sri Lanka - the companies that are best suited to give informed and experience-based information about the digital transformation initiatives and environmental sustainability practices in the workplace.

In the selection of the participants, the researcher adopted purposive sampling, which is a non-probability sampling method that is prevalent in qualitative research. In contrast to random sampling, purposive sampling implies that the participants are selected

deliberately, as they are related to the research questions and can offer accounts that are rich in information regarding the phenomenon under investigation. The sample size in this case was six participants, which was chosen to represent three participants in each organization. These respondents are the senior management executives, who will offer strategic and organizational insights; sustainability specialists, who will offer insights into the environmental objectives and activities; and technology or IT experts, who will offer technical knowledge about the digital systems and their deployment. This cross-functional representation will give the data the ability to capture the phenomenon in various perspectives of every organization.

Table 1. Respondent's Profile (Authors own work).

Respondent No.	Respondent	Background Information
01	Respondent 01	Assistant Manager – Sustainability (Company 01)
02	Respondent 02	Chief Information Officer (Company 01)
03	Respondent 03	Senior Executive – Production (Company 01)
04	Respondent 04	Senior Executive – Sustainability (Company 02)
05	Respondent 05	Head of IT (Company 02)
06	Respondent 06	Assistant Manager – Operations (Company 02)

The primary method of data collection is semi-structured interviews. This type of interview falls between structure and flexibility although there are a few central themes and questions used to direct every interview, the openness of the format gives the participants the freedom to discuss their own experiences, ask unforeseen questions, and use their own language. This is more so in qualitative research where responses are evaluated by their richness and depth rather than being precise in terms of statistics. The major thematic areas addressed in the interviews are the current level of digital maturity in each of the companies, the type and extent of their environmental sustainability

initiatives, their general perceptions and attitudes towards digital transformation, their perception of how digital technologies can help them in engaging in sustainable business operations, and challenges and opportunities they have faced in their attempts to achieve sustainability using digital technologies.

The secondary data is gathered to supplement and confirm the primary data with data sources such as websites of companies, annual reports, industry publications, academic journal articles, and other government reports. This secondary data offers significant background contextual information, aids in supporting the results of the interviews, and contextualizes the two case organizations in the larger context of Sri Lankan industry and global sustainability discourse.

3.3 Data Analysis

Qualitative research analysis is often considered to be one of the most challenging but the most rewarding research phases. In contrast to quantitative analysis where statistical methods are applied, in qualitative analysis, the researcher should be part of the data and make judgements based on interpretation of meaning, pattern, and significance. The thematic analysis in this research is employed as the main mode of analysis because it suits well in determining and explaining patterns of meaning in a collection of interview transcripts.

According to Ayton (n.d.), thematic analysis is a qualitative technique, which is employed to identify, analyze and interpret recurring patterns or themes in data by means of a systematic coding process. Significantly, it does not involve passive and mechanical exercise; it entails the active and reflective involvement of the researcher in developing meaning out of the data but not merely extraction. This fits quite well with the study interpretive philosophy that acknowledges the researcher as a participant in the knowledge-generation process.

The steps of analysis were organized in a systematic manner. The initial phase involved the transcription of all interviews that were recorded to come up with detailed written documents of every interview. The transcripts were then taken through open coding in

the second stage whereby meaningful parts of texts were given descriptive codes that described the content of the utterance. These first codes were then considered and divided into larger categories according to their conceptual resemblances. The last step involved the formation of overarching themes based on these categories, ones that directly address the research questions and help us understand the connection between digital transformation and environmental sustainability in the chosen organizations. In cases where the data uncovered information that went beyond the available theoretical frameworks, the researcher also came up with new theoretical insights to make unique contributions to this discipline. The results will be disseminated in scholarly publications, conferences and industry reports, and will be used to inform the academic discourse as well as the real practice in the manufacturing industry of Sri Lanka.

3.4 Ethical Consideration

Ethical issues were also considered in the study. In this study, the researcher complied with the research ethics of the university and took an ethical route to conducting the research with informed consent. An informed consent form was given to participants electronically before the interview, which explains the objective of the study, confidentiality, and voluntary participation. Since interviews will be done through Microsoft teams or zoom, the participants granted permission to be recorded, and all the recordings will be kept safely and only accessed by a few individuals. No known personal or organizational data will be released without direct permission.

4 Data Presentation and Analysis

4.1 Chapter Introduction

This chapter includes the explanations of findings obtained from six in-depth interviews. All the explanations are built according to the responses given by interviewees regarding the questions asked based on the semi-structured interview guide and have been analyzed thoroughly. To build more effective explanations and analysis related to research questions, all the ideas of each respondent are merged. To come up with theoretical explanations, the researcher has transcript the recorded interviews and categorized important findings under meaningful and related codes. After, based on those codes, researcher has developed themes. This chapter explains the findings regarding created themes for exploring new knowledge regarding research areas.

4.2 Current level of digital transformation

Based on the generic strategy, the results of the analysis generated through coding and sorting of the findings contributed to develop the following themes related to the current level of digital transformation.

Table 2. Themes related to the current level of Digital Transformation (Authors own work).

Digital Technologies	Integration of Technologies into Operations	Specific Software
AI Integration Automation cloud computing Data Analytics Tools E commerce platforms ERP System IoT Implementation MES System		MES Implementation Oracle Technology Power BI SAP HANA ERP Implementation

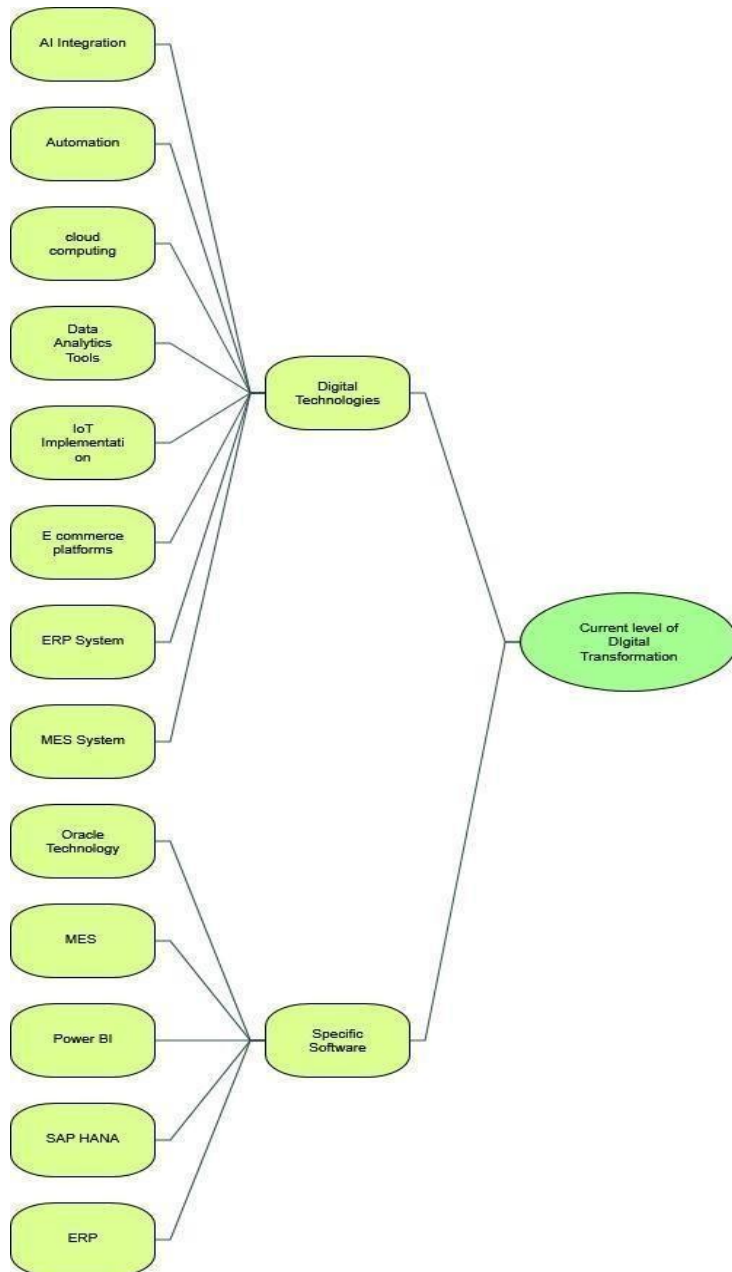


Figure 1. Thematic Framework for current level of Digital Transformation (Author's own work).

4.2.1 Theme 01: Digital Technologies

The major biscuit production companies in Sri Lanka have adopted a broad spectrum of digital technologies not just to increase productivity and competitiveness, but also as a strategic reaction to increasing environmental responsibility. These companies implement digital technologies in production, supply chain management, quality assurance and sustainability programs, having learned that operational efficiency and environmental responsibility are not two agendas anymore, but closely connected. The combination

of IIoT, AI, ERP systems, cloud computing, and advanced data analytics is a comprehensive promise to minimise environmental footprint and stay competitive in the industry.

Respondent 01 - Company 01

"We are using various digital technologies like ERP, which means Enterprise Resource Planning, Automation, Manufacturing Execution System, Industrial Internet of Things likewise." -Excerpt 01-

Respondent 05 - Company 02

"Currently, we employ a suite of digital technologies, including but not limited to the Internet of Things (IoT), Artificial Intelligence (AI), and advanced data analytics." -Excerpt 02-

Respondent 01 - Company 01

"With IIoT sensors and real-time monitoring, we will be able to trace our energy consumption at every production phase, and this information will enable us to identify inefficiencies and minimize the use of resources unnecessarily." -Excerpt 03-

The answers of Respondent 01 in Company 01 and Respondent 05 in Company 02 shed some light on the specific digital technologies that have been implemented by these two major Sri Lankan biscuit manufacturers and, more to the point, the way these technologies contribute towards environmental sustainability. Respondent 01 emphasizes the use of ERP, Automation, Manufacturing Execution System (MES), and Industrial Internet of Things (IIoT). Each of these technologies has a significant impact on the environment, in terms of sustainability. ERP systems provide the possibility of centralized monitoring of resource consumption such as energy, water, and raw material to allow the management to understand wasteful practices and make an informed decision with data that helps to reduce environmental impact. Automation, in its turn, minimizes the material waste by providing control over the production process with precision, thereby minimizing the overproduction and unnecessary use of energy. MES helps in this by allowing

scheduling to be tighter, and real time control of production which reduces idle machine time which is a major contributor of unnecessary energy use in manufacturing facilities. This ability is extended further by IIoT sensors, which allow tracking fine-grained and real-time data on the performance of machinery, providing predictive maintenance to prevent the energy-consuming failures of equipment and unplanned downtime.

Respondent 03 – Company 01

"We are currently using ERP system, Manufacturing Execution System, E-commerce platforms, Automated manufacturing systems and Data analytics." -Excerpt 04-

Respondent 05 of Company 02 focuses on IoT, AI, and advanced data analytics, which, to a certain degree, have the most potential impact on environmental sustainability management. The connected devices IoT allow monitoring energy flows, emissions, and waste streams in every part of the production floor and produces the type of detailed environmental data that had been challenging or impossible to collect in the past. AI extends this data layer by finding patterns and streamlining processes in a manner that would be impossible to accomplish through human supervision, such as dynamically adjusting power use to production demand, or alerting to the presence of inefficiency in raw materials before it gets out of control. High-tech data analytics transforms these findings into practical sustainability indicators, which can help to meet environmental requirements and allow companies to establish and trace quantifiable sustainability objectives.

Respondent 05 – Company 02

"We use cloud computing as a centralized data storage and real-time analysis tool to make decisions based on data across departments."-Excerpt 05-

Respondent 04 – Company 02

“We have Manufacturing Execution Systems (MES) which enable us to track and manage production at the real-time level with resultant optimization of workflows, minimized downtime, and enhanced overall efficiency.” -Excerpt 06-

Respondent 04 - Company 02

“The information that we gather with the help of MES and IoT sensors also provides us with an insight into how much waste we generate and how much energy we consume per batch and with this information we can establish our reduction goals and track our environmental performance.” -Excerpt 07-

Cloud computing, which several respondents from both firms have mentioned, also has a non-recognized role in environmental sustainability. Cloud platforms remove the energy-consuming on-premises server infrastructure that is costly and inefficient for data storage and analytics, while also allowing sustainability data to be accessed by decision-makers throughout the organization at all levels. This openness of data promotes an environmentally conscious culture beyond the committed sustainability departments.

The available literature confirms this congruence between the goals of environmental sustainability and adoption of digital technology. The new technologies that are changing the digital transformation pace are artificial intelligence, big data, cloud computing, and the Internet of Things as Mohamed Hashim et al. (2022) observe. What is more important, these are, in fact, the technologies that the present study relates to the greatest success within the context of environmental performance in manufacturing situations, through optimizing energy, waste reduction, tracking of emissions and smarter resource management. The technologically strong suits of both Company 01 and Company 02 thus are not merely the reaction to the tendencies of global digitalization but rather a conscious, albeit not always explicit, shift towards a more green-friendly mode of operation. These companies are the meeting point of technological innovation and business

responsibility, which proves that in the biscuit production industry, digital transformation and sustainability are becoming more inseparable operational strategies.

4.2.2 Theme 02: Specific Software Used in Companies

Since both companies are in their digital transformation processes, the software platforms they have chosen are one more aspect of the intention to be environmentally sustainable. While the operational benefits of these platforms, efficiency, integration, and productivity are well documented, their capacity to monitor, manage, and reduce environmental impact is equally significant and deserves examination.

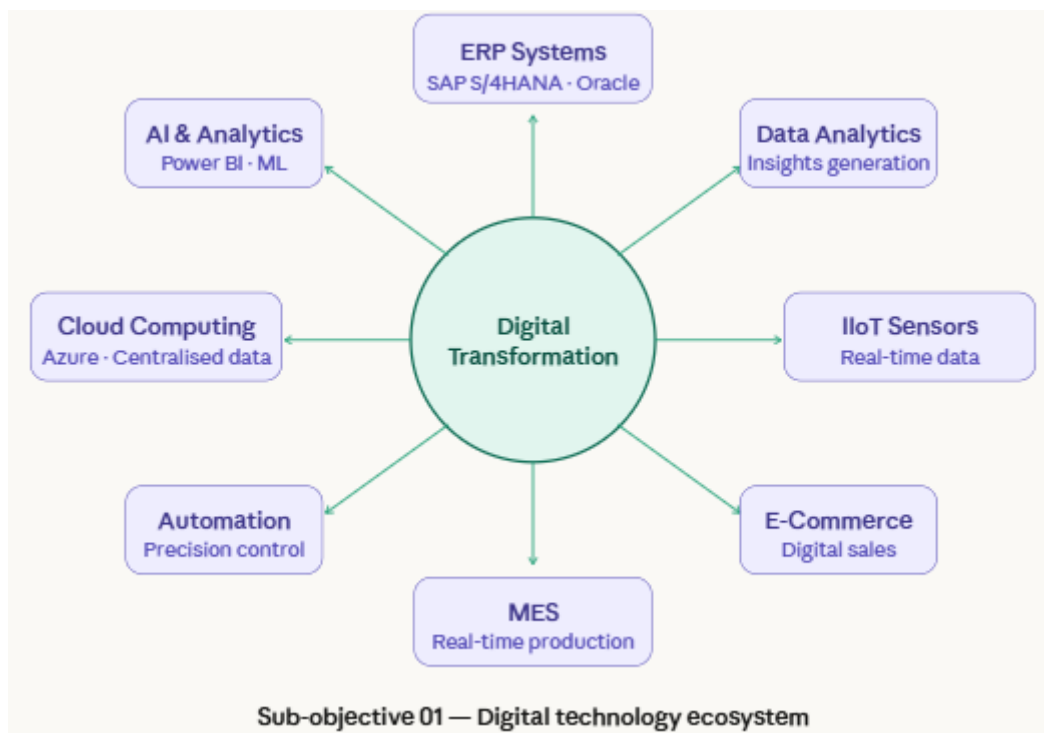


Figure 2. Summary of sub objective 01: Digital technology ecosystem (Author's own work).

Respondent 02 – Company 01

"We've implemented Oracle Technology solutions for enhancing the overall productivity of its manufacturing businesses' sales infrastructure."

"We purchased SAP S/4 HANA for ERP Financial in 2020, Google Workspace (Formerly Google G-Suite) for Collaboration in 2019, Microsoft Azure Cloud Services for Application Hosting and Computing Services in 2019." -Excerpt 08-

Respondent 03 – Company 01

"We use a business analytics solution, Power BI, to help them visualize data and share insights across the organization." -Excerpt 09-

Respondent 02 - Company 01

"SAP S/4HANA enables us to measure our sustainability KPIs such as energy usage per unit produced and waste produced and also enable the management to make decisions that are more environmentally friendly." -Excerpt 10-

The first company in Sri Lanka to implement SAP S/4HANA is company 2 and implemented by Company 01, especially in the context of environmental sustainability. In addition to its own financial and operational competencies, SAP S/4HANA also has inbuilt sustainability management modules, which enable organizations to monitor carbon emissions, energy consumption, and waste indicators in real time and which are built into the same system, which manages the production and financial data. This integration is notable: such that environmental performance is not an isolated activity of a distinct reporting function but rather entrenched in the operational decision-making process of the organization. There is apparent environmental cost implications attached to every production decision, which leads managers toward resource-conscious decisions.

The complementary role can be played by Power BI, which Respondent 03 mentioned. Being a data visualization platform, it allows firms to provide complex environmental data, energy usage patterns, waste amounts, carbon footprint per product line in easy-to-understand, easy-to-act-on formats. With these insights being shared throughout the organization, Power BI facilitates the type of organization-wide environmental consciousness that is necessary to instill sustainability into the daily business culture and not just compliance reporting.

Respondent 05 - Company 02

"We have adopted a state-of-the-art enterprise resource planning (ERP) to provide efficiency to our business processes and thus maximize the efficiency." -Excerpt 11-

Respondent 06 - Company 02

"We are the first company in Sri Lanka to adopt the Business Suite 4 SAP HANA (SAP S/4HANA), which will make a significant contribution in enabling the business processes to be more productive." -Excerpt 12-

Respondent 06 - Company 02

"With SAP S/4HANA, we can create detailed reports on how we use our resources and how we perform in terms of environmental performance that helps us achieve our goal of minimizing our carbon footprint throughout the supply chain." -Excerpt 13-

The Microsoft Azure, which is deployed to facilitate cloud computing and cloud hosting, also makes a smaller, yet significant contribution to environmental sustainability. The nature of cloud infrastructure is that it pools computing resources on shared environments that are operated at scale, which is significantly more energy-efficient than the equivalent on-premises server capacity. With manufacturing companies that have high data processing requirements that are simultaneously migrating to cloud, the direct energy and cooling requirements of local data centers are minimized by MES systems and ERP platforms operating simultaneously.

The software selection decisions of these leading companies thus can be seen to be a two-fold strategic thinking in that they are addressing both short-term operational requirements and a long-term data architecture to measure, report, and continuously improve environmental sustainability performance. These software investments make both companies respond credibly and ahead of the pack in an age of growing regulatory scrutiny and consumer pressure to know more about environmental practices.

4.2.3 Theme 03: Integration of Technology into Operations

The shift of digital technologies into the entire spectrum of the operation of these major biscuit manufacturing companies has far-reaching consequences related to environmental sustainability. Instead of viewing sustainability as a marginal issue that is dealt with by isolated programs, both Company 01 and Company 02 use the profundity and pervasiveness of their technological adoption to show that environmental factors are becoming a part of their own logic of operation.

Respondent 02 - Company 01

“The integration of these technologies allows real time monitoring, less downtime due to predictive maintenance, optimization of inventory and overall production efficiency, thereby boosting competitiveness.” -Excerpt 14-

Respondent 02 - Company 01

“Not only does predictive maintenance assist us in stopping production downtime, but it also ensures that we are not subjected to excessive energy consumption like machines working under stress, which is clearly an environmental benefit as well.” -Excerpt 15-

In view of environmental sustainability, every operational advantage listed by Respondent 02 comes with an environmental dividend attached to it. Real-time monitoring allows constant access to energy use, water use, and waste production and turns these into regular audit issues to real-time operational variables. Predictive maintenance, in addition to its cost-saving role, eliminates the energy wastefulness that is inherent in the operation of a machine under conditions of degradation; a machine nearing breakdown will generally consume more energy and produce more waste than a machine functioning within its optimal range. Optimal inventory allows to lower the environmental costs of overproduction and too much storage as well as wasteful transportation, all of which are a part of the overall carbon footprint of the firm. And improved efficiency in production, in its turn, is the ability to produce more by using less: less energy, fewer raw

materials, and less waste per unit of production. These are exactly what environmental sustainability models aim at realizing.

Respondent 05 – Company 02

"It is these digital technologies that are very much embedded in the entire business processes- production and supply chain management, quality control and customer relations are areas where digital technologies have been of great essence in streamlining our processes and bringing about a seamless coordination of various departments."-Excerpt 16-

Respondent 05 - Company 02

"Our supply chain digitization has enabled us to collaborate more with suppliers on sustainability standards, we can now trace material sourcing more precisely and select suppliers on their environmental credentials." -Excerpt 17-

The degree of integration outlined by respondent 05 of Company 02 involves production, supply chain management, quality control, and customer relations, which are individual domains with different environmental sustainability significance. Digital integration in the supply chain management allows higher levels of traceability of the raw materials, which in turn helps in the selection of suppliers who are environmentally friendly and lowers the chances of sourcing materials that are related to deforestation, high carbon mining, or unsustainable farming methods. Digital monitoring in quality management lowers the number of defects and material wastage; each batch that does not pass quality checks implies a wastage of raw materials, wastage of energy, and even wastage of emissions. Digital platforms, in the context of customer relations, open the floor to communicate environmental commitments of the firm and receive feedback that can be used to make the product more sustainable.

This broad integration is closely related to the definition by Kraus et al. (2022), who describe digital transformation as the use of digital technology in all parts of an

organization. This leads to major changes in how the organization operates and how it creates value for its customers.

From an environmental sustainability perspective, this idea becomes even more important. When digital technology is used across all activities, it helps organizations improve efficiency and supports better environmental responsibility. Such changes influence data management, decision-making, transparency of supply chain and resource utilization. Subsequently, organizations will be able to proceed beyond merely complying with environmental regulations to actively engage in the management of sustainability based on data and informed decision-making.

The biscuit manufacturing firms examined in this study therefore illustrate a pattern that is increasingly recognized in sustainability research: digital transformation, when deeply integrated rather than superficially applied, does not merely support environmental sustainability as a secondary benefit, it becomes one of its most powerful enabling mechanisms.

Table 3. Summary Table for Current level of Digital Transformation.

Theme	Meaning	Evidence
Digital Technologies	This explains the different kinds of digital technologies that are currently used in biscuit manufacturing firms. Mention with their names and explain the use of those	<p>“We are using various digital technologies like, ERP, it means Enterprise Resource Planning, Automation, Manufacturing Execution System, Industrial Internet of things likewise.”</p> <p>Respondent 01 – Company 01</p> <p>“With IIoT sensors and real-time monitoring, we will be able to trace our energy consumption at every production phase, and this information will</p>

	<p>technologies within the company.</p>	<p>enable us to identify inefficiencies and minimize the use of resources unnecessarily.”</p> <p>Respondent 01 - Company 01</p> <p>“Currently, we employ a suite of digital technologies, including but not limited to the Internet of Things (IoT), Artificial Intelligence (AI), and advanced data analytics.”</p> <p>Respondent 05 – Company 02</p> <p>"We are currently using ERP system, Manufacturing Execution System, E-commerce platforms, Automated manufacturing systems and Data analytics."</p> <p>Respondent 03 – Company 01</p> <p>"We use cloud computing as a centralized data storage and real-time analysis tool to make decisions based on data across departments.”</p> <p>Respondent 05 – Company 02</p> <p>“We have Manufacturing Execution Systems (MES) which enable us to track and manage production at the real-time level with resultant optimization of workflows, minimized downtime, and enhanced overall efficiency.”</p> <p>Respondent 04 – Company 02</p> <p>"The information that we gather with the help of MES and IoT sensors also provides us with an insight into how much waste we generate and how much</p>
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		<p>energy we consume per batch and with this information we can establish our reduction goals and track our environmental performance.”</p> <p>Respondent 04 - Company 02</p>
<p>Specific Software that uses in company</p>	<p>This explains the specially installed software for getting more efficient output and enhance operational effectiveness. This includes the relevant software names, specific work and how it helps to enhance business operations.</p>	<p>“We've implemented Oracle Technology solutions for enhancing the overall productivity of its manufacturing businesses’ sales infrastructure”</p> <p>Respondent 02 - Company 01</p> <p>“We purchased SAPS/4 HANA for ERP Financial in 2020, Google Workspace (Formerly Google G-Suite) for Collaboration in 2019, Microsoft Azure Cloud Services for Application Hosting and Computing Services in 2019 and the related IT decision-makers and key stakeholders”</p> <p>Respondent 02 - Company 01</p> <p>“We use business analytics solution, Power BI, to help them visualize data and share insights across the organization”</p> <p>Respondent 03 – Company 01</p> <p>"SAP S/4HANA enables us to measure our sustainability KPIs such as energy usage per unit produced and waste produced and also enable the management to make decisions that are more environmentally friendly.”</p> <p>Respondent 02 - Company 01</p>

		<p>"We have adopted a state-of-the-art enterprise resource planning (ERP) to provide efficiency to our business processes and thus maximize the efficiency."</p> <p>Respondent 05 - Company 02</p> <p>"We are the first company in Sri Lanka to adopt the Business Suite 4 SAP HANA (SAPS/4HANA), which will make a significant contribution in enabling the business processes to be more productive."</p> <p>Respondent 06 – Company 02</p> <p><i>"With SAP S/4HANA, we can create detailed reports on how we use our resources and how we perform in terms of environmental performance that helps us achieve our goal of minimizing our carbon footprint throughout the supply chain."</i></p> <p>Respondent 06 - Company 02</p>
<p>Integration of technology into business operation</p>	<p>This explains how above-mentioned technologies support overall business operations. The way of affecting these technologies into business excellence and explain the connection between</p>	<p>"The integration of these technologies allows real time monitoring, less downtime due to predictive maintenance, optimization of inventory and overall production efficiency, thereby boosting competitiveness."</p> <p>Respondent 02 – Company 01</p> <p>"Not only does predictive maintenance assist us in stopping production downtime, but it also ensures that we are not subjected to excessive energy</p>

	<p>technology and the business operation.</p>	<p>consumption like machines working under stress, which is clearly an environmental benefit as well.”</p> <p>Respondent 02 - Company 01</p> <p>“It is these digital technologies that are very much embedded in the entire business processes- production and supply chain management, quality control and customer relations are areas where digital technologies have been of great essence in streamlining our processes and bringing about a seamless coordination of various departments.”</p> <p>Respondent 05 - Company 02</p> <p>“Our supply chain digitization has enabled us to collaborate more with suppliers on sustainability standards, we can now trace material sourcing more precisely and select suppliers on their environmental credentials.”</p> <p>Respondent 05 - Company 02</p>
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4.3 Existing environmental sustainability practices

Based on the generic strategy, the results of the analysis generated through coding and sorting of the findings contributed to develop the following themes related to the existing environmental sustainability practices in leading biscuit manufacturing firms in Sri Lanka.

Table 4. Themes related to existing sustainability practices (Authors own work).

Environmental Sustainability Initiatives	Enhance the sustainability performance through Digital Technologies
Energy and Carbon Reduction Water Conservation Waste Reduction and circular economy practices Sustainable Packaging	Real-Time Environmental Monitoring and Energy Management AI-Driven Process Optimization for Emission and Waste Reduction Supply Chain Environmental Transparency Waste Reduction Through Digital Precision Sustainability Reporting and Goal setting

4.3.1 Theme 01: Environmental Sustainability Initiatives

The major biscuit producers in Sri Lanka have been realizing that environmental sustainability is not just a compliance issue but a strategic necessity that determines their future competitiveness and social legitimacy. With increasing knowledge of the environmental impact of industrial food production such as greenhouse gas emissions, water use, solid waste, and packaging waste, such firms have shifted their environmental management efforts to active, multi-dimensional sustainability initiatives as part of their business processes.

Their sustainability initiatives encompass the whole production process. This involves the sourcing of raw materials in a more sustainable agricultural manner, efficiency in the utilization of energy and water in its production and proper management of waste and packaging. Companies no longer view these actions as distinct activities, but are becoming more integrated, with the environmental factors being taken into consideration in investments, utilization of technologies, and day-to-day operations.

This is particularly significant in the production of biscuits, where the production process is associated with energy-consuming baking, a lot of packaging material, and a lot of

water consumed in the cleaning and processing of the product. Such activities may impact on the environment greatly without proper management and thus, sustainability is a major concern in industry.

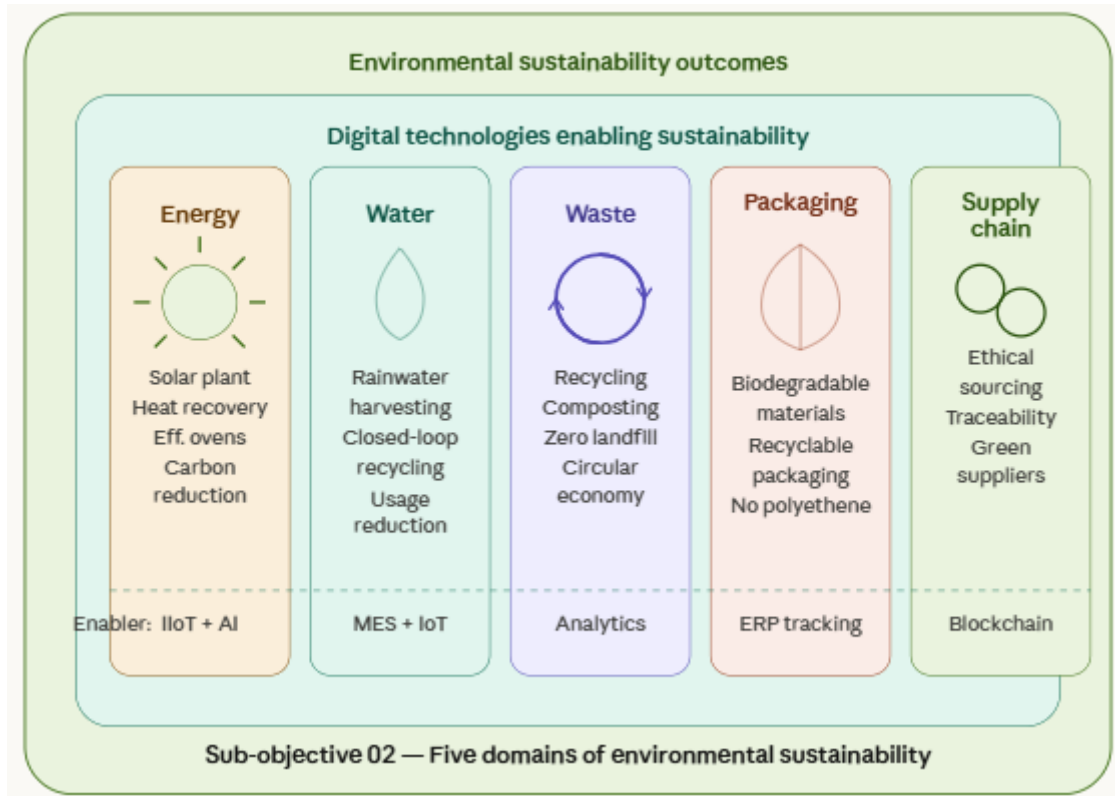


Figure 3. Summary of sub objective 02: Five domains of Environmental sustainability (Author's own work).

Energy and Carbon Reduction

Respondent 01 – Company 01

"We have already generated clean energy for our manufacturing facility through a solar power plant. Responsible for reducing water usage through process improvement and rainwater harvesting. And we have implemented a waste reduction program. It enables diverted waste from landfills through recycling and composting. When it comes to packaging materials, we used polyethene covers before and we are now using biodegradable and recyclable packaging materials". -Excerpt 18-

Respondent 04 – Company 02

“Our environmental sustainability programs are varied. We have introduced energy saving technologies in our production and as a result our carbon footprint has been reduced significantly, we have also taken to recycling and we are also using eco-friendly packaging materials, which has made our supply chain more sustainable.”-Excerpt 19-

Respondent 03 – Company 01

“Before digital transformation, we had very little insight into how much energy each unit of the production line was using, now with real time monitoring systems we are able to know which machines are the biggest energy consumers and make specific action to decrease that.” -Excerpt 20-

Installation of a solar power plant by Company 01 as explained by Respondent 01 is one of the most important capital investments that a manufacturing firm can make in terms of environmental benefit. The production of renewable energy on-site means that the company will directly decrease its reliance on fossil fuel-based grid electricity in the Sri Lankan environment, which has a significant carbon intensity, which further decreases the overall greenhouse gas emission per unit of production of the company. It is not a simple energy saving solution, but a planned decarbonization which deals with one of the most significant environmental effects of biscuit production: the energy requirements of the ongoing baking, mixing, and packaging processes.

The implementation of energy-efficient technologies in production processes, as mentioned by Respondent 04, in Company 02 is a complementary strategy towards reducing the carbon footprint. Although the excerpt does not mention specific technologies, energy-saving manufacturing generally includes high-efficiency ovens and motors, heat recovery systems, which recapture and reuse thermal energy consumed in the baking process, variable speed drives, which use less electricity during the production phases of low demand, and LED lighting upgrades, which are associated with the manufacturing

floors and warehouses. All these interventions can produce significant operational carbon emission cuts.

Respondent 06 – Company 02

“We have invested in energy efficient oven systems and heat recovery technology which captures the heat emitted during the baking process and diverts it to other areas within the facility and this has really cut down on our overall energy usage and related emissions.”-Excerpt 21-

Water Conservation

Another important area of environmental sustainability that biscuits manufacture should focus on is water management, as huge amounts of water are used in processing ingredients, cleaning of equipment, and maintenance of the facility. The two-pronged strategies of Company 01, which is the integration of process enhancement to achieve economization of water used in the production process and the use of rainwater to supplement the water supply, portrays a high level of water stewardship that includes the demand and supply side of the water issue. The improvement of the process under this context can be the introduction of the dry-cleaning technology of equipment maintenance, closed loop water recycling, and the accuracy of water dosing when making dough to remove the unnecessary use. Rainwater harvesting, in its turn, enhances the independence of the firm both on municipal/groundwater, and on the issues of local water stress, which is of specific environmental importance considering the uneven distribution of rainfall in Sri Lanka and the problems of water stress in the area.

Respondent 01 – Company 01

“Our washing and cleaning processes have also been introduced to a closed-loop water recycling system which has enabled us to greatly reduce our freshwater consumption with a combination of our rainwater harvesting system and reduces our reliance on external sources of water.” -Excerpt 22-

Waste Reduction and Circular Economy Practices

The waste reduction program of Company 01, which actively redirects waste out of landfill by means of recycling and composting, is a manifestation of interaction with the principles of a circular economy, which is becoming one of the main priorities in environmentally friendly manufacturing. Examples of the waste streams in the biscuit manufacturing setting are the production of offcuts and broken biscuits, flour and ingredient dusting, packaging offcuts, and organic residues during ingredient processing. Using these streams to recycle or turn into compost instead of placing them in landfill, Company 01 will save on the emission of methane during the decomposition of organic waste, recover material value, and reduce its impact on the overall solid waste buildup. The fact that Company 02 is taking part in parallel in recycling programs also proves that the concept of recycling waste as a form of circularity has become an industry-wide green agenda, as opposed to a one-off event.

Respondent 04 – Company 02

"We have set up a system where production waste including biscuit offcuts and packaging material offcuts is sorted and sent to certified recycling partners rather than going to landfill. We also recycle our organic material and seek to utilize it in agriculture, which is in line with our overall pledge towards a circular economy." -Excerpt 23-

Sustainable Packaging

Recyclable and biodegradable packaging like the one mentioned by Respondent 01 is one of the most noticeable and consumer-facing environmental sustainability pledges made by these companies. One of the largest sources of post-consumer environmental pollution in the food manufacturing industry is conventional plastic packaging, which has been piled up over the decades in landfills, waterways, and ecosystems. Company 01 is minimizing the downstream environmental impact of its products by replacing them with biodegradable and recyclable products by recognizing that its environmental responsibility does not stop at the factory door but continues through the entire lifecycle of its packaging. The use of eco-friendly packaging materials at Company 02 is also an

indication of the awareness that sustainable packaging should not only be a policy that the company uses to help the environment, but also a competitive edge in a market where consumer awareness of the environment is on the increase.

Respondent 03 – Company 01

"The shift to biodegradable packaging was driven partly by our own environmental commitments and partly by what we were seeing from consumers. An increasing pressure is being exerted on the companies which they acquire to have responsibility in packaging waste, and we were eager to be in the lead of that." -Excerpt 24-

Collectively, these environmental sustainability efforts, including renewable energy, energy efficiency, water conservation, waste reduction, and sustainable packaging, give a portrait of companies that have long since passed the bare minimum regulatory requirements. Company 01 and Company 02 actively transform their business models based on environmental responsibility, and each of their activities covers another aspect of their impact on the environment, although these aspects are different yet interdependent. One of the interesting aspects is that it is a systemic form of engagement; these firms are not seeking to develop individual green projects: instead, they are embedding environmental sustainability within the structural logic of their manufacturing, sourcing and delivering their product.

4.3.2 Theme 02: Enhancing Environmental Sustainability Performance Through Digital Technologies

The environmental sustainability initiatives outlined in Theme 01 are not independent of the digital transformation pathways that these companies are undertaking. Quite the contrary, the respondent data show that there is a very consequential relationship between the two: digital transformation is serving as the operating undercarriage that is enabling ambitious environmental sustainability goals to be measured, manageable, and constantly upgraded. This theme explores how certain digital technologies and platforms are empowering Company 01 and Company 02 to take their environmental sustainability

performance to the next level, which they were unable to achieve using traditional methods of management.

Respondent 01 – Company 01

"Digital transformation has also made it possible to optimize the use of resources, minimize waste, and improve visibility of supply chains, which has a positive effect on environmental sustainability."-Excerpt 25-

Respondent 05 – Company 02

"Digital transformation is significant in assisting us to establish and realize high sustainability targets. We are in a better position to align our business goals with sustainable practices by adopting technology to streamline operations, minimize wastes, and develop innovation."-Excerpt 26-

Respondent 01 – Company 01

"Before we had these digital systems in place, our sustainability strategy was mostly manual and reactive, and we would detect an issue once it had already led to waste or overconsumption. We are now able to identify such problems in real-time and react instantly and this has contributed immensely to our environmental performance."-Excerpt 27-

The contrast drawn between pre- and post-digital transformation environmental management practices is particularly revealing. Prior to digital transformation, environmental monitoring in manufacturing firms was typically conducted through periodic manual audits, batch-level reporting, and retrospective data analysis and approaches that inherently lag operational reality and limit the speed and precision of corrective action. The shift to real-time digital monitoring fundamentally changes this dynamic. As Respondent 01 of Company 01 indicates, digital transformation has enabled the optimization of resource usage, a statement that, in the context of environmental sustainability, encompasses energy consumption, water usage, raw material efficiency, and waste generation

simultaneously. Monitoring and being able to optimize these variables in real time instead of periodically reviewing these variables enables the firm to detect and rectify environmental inefficiencies as they arise, as opposed to them occurring, and causing their entire environmental cost.

Real-Time Environmental Monitoring and Energy Management

Respondent 06 – Company 02

“Our IoT sensors give us a real-time view of energy consumption across the entire production line. We can see the machines that are consuming more power than it should, detect inefficiencies and adjust them immediately. Such visibility could not have been achieved in the pre-digital transformation era and it has been transformational in our energy management.”-Excerpt 28-

The implementation of IIoT sensors and MES platforms, which are addressed in the framework of the adoption of digital technologies in Section 4.2, is directly translated into the improvement of environmental sustainability when applied to energy and resource monitoring. These systems can help production managers identify energy hotspots and individual machines or process stages that consume disproportionate amounts of electricity and implement specific corrective measures because they provide continuous and granular information on energy consumption at equipment level. This accuracy was not possible during the pre-digital period when it was usually only possible to monitor energy in monthly facility-level electricity bills. The change in the retrospective facility level data into real-time equipment level data is a qualitative change in the capacity of the firm to actively control its carbon footprint instead of passively.

AI-Driven Process Optimization for Emission and Waste Reduction

The application of artificial intelligence in improving environmental sustainability performance is not limited to energy monitoring but also to the optimization of the active processes. The patterns of resource inefficiency, which are too dynamic and difficult to observe manually, can be discovered by AI algorithms and trained on the operational data

provided by the IoT sensors and MES platforms. In the production of biscuits, this could involve the dynamic adjustment of oven temperature and baking duration to match the real time dough properties in order to use less energy and still produce the same quality product, the dosing of ingredients to produce less raw material waste in each batch, or the production run could be scheduled in advance to avoid the energy-intensive stop and start cycles of reactive scheduling.

Respondent 04 – Company 02

“Our AI-based analytics are used to constantly optimize our baking parameters. The system is informed by the production data and uses settings to reduce the use of energy and yet retain the quality levels. This has saved us per unit energy consumption compared to manual process control.”-Excerpt 28-

Supply Chain Environmental Transparency

The fact that respondent 02 mentions that digital transformation allows improving supply chain visibility is especially important regarding environmental sustainability. The scope 3 emissions commonly known as supply chain emissions in carbon accounting systems can be the largest portion of the total carbon footprint of a food company, including the emissions of raw material farming, transportation of ingredients, energy consumption by suppliers, and disposal of end-of-life packaging. By facilitating real-time tracking of materials back to source through to the production floor, digital supply chain platforms enable companies to control and impact the environmental performance of its supply chains in a manner that was once impractical. This involves the process of choosing suppliers, who have proven environmental credentials, optimizing transportation routes to minimize logistics emissions, and making sure that packaging materials are certified as sustainable.

Respondent 02 – Company 01

“We are far more aware of where our raw materials are being sourced and how our suppliers practice environmental responsibility with our ERP tools and digital supply

chains. This has enabled us to focus on suppliers that are in line with our sustainability requirements and this has minimized the environmental impact of our whole supply chain.”-Excerpt 29-

Waste Reduction Through Digital Precision

The relationship between digital transformation and waste reduction as defined by both respondents reveals that there has been a drastic change in the way the firms interpret and deal with waste. Traditional manufacturing views waste as an inevitable by-product of production and is subsequently dealt with either by disposal or recycling. Digital transformation, however, alters this opinion and considers waste as an indicator of wastefulness in the production process.

Through the application of data analytics to production data, companies can determine the exact factors that result in increased amounts of waste: machine settings, raw materials batches, and environmental factors. This enables companies to prepare and avoid waste even before it happens. Consequently, this proactive, upstream solution is not just greener, but also cheaper than conventional, downstream waste management solutions.

Respondent 04 – Company 02

“We were starting to handle waste once created before being digitally transformed. We now apply data analytics to see why waste is being created and solve the underlying issue in the production process. This has enabled us to greatly minimize waste at the source and not just manage it at the end.” -Excerpt 30-

Sustainability Reporting and Goal setting

Lastly, digital transformation has significantly increased the ability of these firms to report on environmental sustainability and set goals, which are the pillars of constant improvement. SAP S/4HANA and other platforms mentioned in Section 4.2 offer sustainability performance modules, which allow companies to monitor the following key environmental indicators: energy intensity per unit produced, water consumption per batch,

carbon emissions, and waste diversion rates in comparison to set goals, and to create plausible reports to internal management, regulatory agencies, and other external stakeholders. The presence of such data infrastructure makes environmental sustainability not a narrative commitment, but a measurable performance and whose management is equally rigorous as other key performance indicators such as financial or production.

Respondent 05 – Company 02

“SAP S/4HANA has also provided us the opportunity to monitor our sustainability KPIs in the same rigorous way our financial KPIs are monitored. Our carbon emissions, energy consumption and waste indicators can be tracked against targets in real-time and this has brought our sustainability objectives to life and made them more practical.” -Excerpt 31-

This dynamic is well summed up by respondent 05 of Company 02: digital transformation is not simply allowing the firm to become more sustainable in the current. It is helping the company to make more ambitious sustainability targets and be able to monitor progress toward them with the data rigor that true accountability demands. The technological capability and sustainability ambition outlined by both companies is representative of a larger reality that is being revealed by the literature and validated by these results: in the modern manufacturing world, the companies who have developed the digital infrastructure to measure, manage, and constantly enhance their environmental performance are the ones that are well-equipped to attain significant environmental sustainability results. To major biscuit producers in Sri Lanka, digital transformation has become an inalienable part of their environmental sustainability process.

Table 5. Summary Table for Existing Sustainability Practices.

Theme	Meaning	Evidence
Environmental	This includes the sustainability	"We have already generated clean energy for our manufacturing facility through a solar

Sustainability Initiatives	practices that are used in each biscuit manufacturing company related to environmental dimensions.	<p>power plant. Responsible for reducing water usage through process improvement and rainwater harvesting. And we have implemented a waste reduction program. It enables diverted waste from landfills through recycling and composting. When it comes to packaging materials, we used polyethene covers before and we are now using biodegradable and recyclable packaging materials”.</p> <p>Respondent 01 – Company 01</p> <p>“Our environmental sustainability programs are varied. We have introduced energy saving technologies in our production and as a result our carbon footprint has been reduced significantly, we have also taken to recycling and we are also using eco-friendly packaging materials, which has made our supply chain more sustainable.”</p> <p>Respondent 04 – Company 02</p> <p>“Before digital transformation, we had very little insight into how much energy each unit of the production line was using, now with real time monitoring systems we are able to know which machines are the biggest energy consumers and make specific action to decrease that.”</p> <p>Respondent 03 – Company 01</p> <p>“We have invested in energy efficient oven systems and heat recovery technology which</p>
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		<p>captures the heat emitted during the baking process and diverts it to other areas within the facility and this has really cut down on our overall energy usage and related emissions.”</p> <p>Respondent 06 – Company 02</p> <p>“Our washing and cleaning processes have also been introduced to a closed-loop water recycling system which has enabled us to greatly reduce our freshwater consumption with a combination of our rainwater harvesting system and reduces our reliance on external sources of water.”</p> <p>Respondent 01 – Company 01</p> <p>“We have set up a system where production waste including biscuit offcuts and packaging material offcuts is sorted and sent to certified recycling partners rather than going to landfill. We also recycle our organic material and seek to utilize it in agriculture, which is in line with our overall pledge towards a circular economy.”</p> <p>Respondent 04 – Company 02</p> <p>“The shift to biodegradable packaging was driven partly by our own environmental commitments and partly by what we were seeing from consumers. An increasing pressure is being exerted on the companies which they acquire to</p>
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		<p>have responsibility in packaging waste, and we were eager to be in the lead of that."</p> <p>Respondent 03 – Company 01</p>
<p>Enhance sustainability performance through Digital Technologies</p>	<p>This theme explains how digital technologies are impacted by existing sustainability practices in each company. Sustainability performance is affected by the digital transformation initiatives. This is exploring the ultimate performance of sustainability.</p>	<p>"Digital transformation has also made it possible to optimize the use of resources, minimize waste, and improve visibility of supply chains, which has a positive effect on environmental sustainability."</p> <p>Respondent 01 – Company 01</p> <p>"Digital transformation is significant in assisting us to establish and realize high sustainability targets. We are in a better position to align our business goals with sustainable practices by adopting technology to streamline operations, minimize wastes, and develop innovation."</p> <p>Respondent 05 – Company 02</p> <p>"Before we had these digital systems in place, our sustainability strategy was mostly manual and reactive, and we would detect an issue once it had already led to waste or overconsumption. We are now able to identify such problems in real-time and react instantly and this has contributed immensely to our environmental performance."</p> <p>Respondent 01 – Company 01</p>

		<p>Our IoT sensors give us a real-time view of energy consumption across the entire production line. We can see the machines that are consuming more power than it should, detect inefficiencies and adjust them immediately. Such visibility could not have been achieved in the pre-digital transformation era, and it has been transformational in our energy management.”</p> <p>Respondent 06 – Company 02</p> <p>“Our AI-based analytics are used to constantly optimize our baking parameters. The system is informed by the production data and uses settings to reduce the use of energy and yet retain the quality levels. This has saved us per unit energy consumption compared to manual process control.”</p> <p>Respondent 04 – Company 02</p> <p>“We are far more aware of where our raw materials are being sourced and how our suppliers practice environmental responsibility with our ERP tools and digital supply chains. This has enabled us to focus on suppliers that are in line with our sustainability requirements and this has minimized the environmental impact of our whole supply chain.”</p> <p>Respondent 02 – Company 01</p>
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		<p>“We were starting to handle waste once created before being digitally transformed. We now apply data analytics to see why waste is being created and solve the underlying issue in the production process. This has enabled us to greatly minimize waste at the source and not just manage it at the end.”</p> <p>Respondent 04 – Company 02</p> <p>“SAP S/4HANA has also provided us the opportunity to monitor our sustainability KPIs in the same rigor way our financial KPIs are monitored. Our carbon emissions, energy consumption and waste indicators can be tracked against targets in real-time and this has brought our sustainability objectives to life and made them more practical.”</p> <p>Respondent 05 – Company 02</p>
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4.4 Perceived Benefits and Risks of Digital Transformation in Enhancing Environmental Sustainability

Based on the generic strategy, the results of the analysis generated through coding and sorting of the findings contributed to develop the following themes related to the perceived benefits and risks of digital transformation in enhancing environmental sustainability within leading biscuit manufacturing firms in Sri Lanka.

Table 6. Themes related to Perceived Benefits and Risks of Digital Transformation (Author' own work).

Benefits of Digital Transformation	Risks and Challenges of Digital Transformation	Mitigation Strategies	Future Plans
Energy efficiency gains Waste reduction Carbon footprint reduction Supply chain transparency Enhanced environmental reporting	Initial investment costs E-waste generation Data security risks Skills and capability gaps Energy consumption of digital infrastructure	Phased implementation Responsible disposal practices Cybersecurity frameworks Training and development Renewable energy powering digital systems	Green technology integration Carbon neutrality goals AI-driven sustainability Circular economy advancement Sustainable supply chain digitization

4.4.1 Theme 01: Benefits of Digital Transformation for Environmental Sustainability

The adoption of digital technologies into the work of the major Sri Lankan manufacturing companies in the biscuit sector has produced a set of practical and extended environmental sustainability advantages. These advantages go far beyond the type of operational efficiencies often mentioned in the business transformation literature. They are quantifiable updates in the ecological footprints of the firms, whether in a decrease in carbon emissions and energy usage or superior waste management and supply chain environmental responsibility. In the case of both Company 01 and Company 02, digital transformation has served as an enabling mechanism that turns the goals of environmental sustainability into a working reality, which offers the measurement specificity, process management, and systemic visibility needed to make meaningful and verifiable environmental progress.

Energy Efficiency and Carbon Footprint Reduction

One of the greatest environmental positive effects that the respondents reported includes the massive energy efficiency using digital monitoring and process optimization. Before the process of digital transformation, energy management in the production of

biscuits was mostly a passive process. Companies used the energy as a fixed cost of operation and could not comprehend or control the consumption patterns on a micro level. This has been revolutionized by the implementation of IoT sensors and MES platforms, and AI-based analytics, which allow companies to track the energy consumption in real time at equipment-level and dynamically optimize processes to reduce the unnecessary energy draw.

Respondent 01 – Company 01

"Digital transformation has yielded one of the greatest advantages to us in the form of a reduction in our energy consumption. Through tracking our production line in real time, we realized that there were various areas where we were wasting energy and machines left running when they're not being used, poor oven temperature controls and we dealt with these systematically. Since we installed these digital systems our energy consumption per unit of production has significantly decreased." -Excerpt 32-

Respondent 05 – Company 02

"Our carbon footprint reduction strategy has focused on digital transformation. With the optimization of the processes through AI, we have managed to make our baking activities much energy intensive. The system continually regulates parameters in accordance with real-time information, and the energy efficiency of the system is possible in a way that would be impossible under manual control." -Excerpt 33-

The importance of energy efficiency gains in the production of biscuits to the environment cannot be exaggerated. One of the most energy-consuming processes of biscuit production is baking, and a slight increase in the efficiency of the oven results in significant carbon emissions reduction based on the scale of the ongoing industrial production. Such energy savings provided by digital optimization, together with the renewable energy production efforts outlined in Section 4.3, including the solar power plant of Company 01, further decrease the carbon footprint, which puts these companies on a plausible path to low-carbon production.

Waste Reduction and Circular Economy Advancement

The digital transformation has also provided quantifiable environmental impact in the field of waste management. As explained in Section 4.3, waste management in such companies has ceased to be a reactive, end-of-pipe initiative and is now a data-driven, proactive approach. The capacity to scrutinize the data on production and find the very origins of waste production instead of just handling the waste once it has been created is a qualitative aspect of the environment that digital technologies have enabled.

Respondent 03 – Company 01

“Prior to the digital transformation, we were producing an immense amount of waste during production that we could hardly justify or avoid. Since the adoption of our data analytics systems, we have been able to track the waste to process variables and rectify them at the source. Our batch waste has been minimized significantly, and this is of benefit to the environment and the cost.”-Excerpt 34-

Respondent 04 – Company 02

“Our analytics systems and MES have provided us with a far more accurate understanding of waste production points of our production process. We now conduct regular waste reduction reviews using real data as opposed to estimates and as such, we have been able to establish and accomplish more ambitious waste reduction targets.”-Excerpt 35-

In addition to production waste, digital transformation has enabled these firms to improve their capacity to promote the practice of the circular economy in all their operations. Digital supply chains allow a more accurate forecast of demand, which minimizes overproduction, which is one of the largest areas of food and material waste in the production process. The use of smart inventory management systems reduces chances of spoilage of raw materials since the ingredients are used within the best time frames. All these abilities are part of a more circular operation model where resources are utilized to the full extent and waste streams are reduced to a minimum.

Supply Chain Environmental Transparency and Responsible Sourcing

Another positive impact of digital transformation on the environment mentioned by the respondents is the improvement of supply chain visibility, the possibility to trace the materials source to the production floor and to check the suppliers and sourcing practices environmental requirements. The supply chain visibility is not just a compliance tool in an industry where the raw material agriculture, ingredient transportation, and packaging manufacturing have large environmental footprints but in fact a true tool to decrease the overall lifecycle environmental impact.

Respondent 02 – Company 01

“Through our digital supply chain platform, we are now able to trace our raw materials back to its source and ensure our suppliers are living up to our environmental standards. This has enabled us to make better sourcing choices and to collaborate with suppliers to enhance their environmental activities, which, when our supply chain information was in pieces, was merely not possible as it was then manual.”-Excerpt 36-

Respondent 06 – Company 02

“Digitization of the supply chain has turned around our sustainability agenda. Now we can trace the carbon intensity of our sourcing of ingredients, to trace certifications of the packaging materials and to assess the environmental performance of suppliers in a systematic way. This provides the information to make truly sustainable sourcing choices as opposed to self-reported information by suppliers.”-Excerpt 37-

Enhanced Environmental Reporting and Accountability

The digital transformation has also created a lot of benefits in terms of environmental performance measurement, reporting, and accountability. The implementation of integrated ERP systems, specifically the SAP S/4HANA, have given both corporations the data framework to monitor environmental KPIs in the same spirit of strictness that financial and operational metrics have followed. The ability forms the basis of plausible

environmental sustainability management: unless one has trustworthy, granular environmental information, sustainability commitments will remain aspirational, but not operational.

Respondent 05 – Company 02

“We have digital systems that have revolutionized our capacity to report on environmental performance. Now we can compile detailed reports on our carbon emissions, our energy usage, our water usage and our waste generation at any given point in time, in terms of our production line, product category or time period. Such reporting was unthinkable in the pre-digital transformation era, and it has rendered our sustainability commitments much more believable and realistic.”-Excerpt 38-

Compliance with the ever-stricter regulatory requirements and alignment with the internationally accepted environmental reporting standards are also facilitated by the environmental reporting capabilities made possible by digital transformation. With the increasing regulatory pressures on the environmental performance of manufacturing firms, both at the international level and in Sri Lanka, the manufacturing firms that have invested in digital environmental data infrastructure are better placed to prove that they comply with the requirements, answer the questions of stakeholders, and take the initiative to report their environmental performance.

Success Stories and Positive Environmental Outcomes

Both companies have documented tangible, quantifiable environmental impacts, which they directly credited to their digital transformation initiatives, impacts that can be viewed as compelling testimony to the practical value of digital technologies which can have on the environment within the biscuit manufacturing environment.

Respondent 01 – Company 01

“Among the success stories, I would mention our solar power plant combined with our digital energy management system. Prior to the digital revolution, despite the

installation of the solar panels, we were not maximizing our energy consumption patterns to match the solar generation peaks. After we incorporated the digital energy management system, we were able to dynamically adjust energy intensive production to peak solar generation times which maximized our utilization of renewable energy and further minimized our dependence on grid power. This integration has also saved a lot of carbon.”-Excerpt 39-

Respondent 06 – Company 02

“One of the positive changes that I would mention is our reduction of water consumption. By operating in real time on the amount of water used in our cleaning and processing processes, and by optimizing our water recycling systems using AI, we managed to cut the amount of freshwater consumed within the initial year of complete digital integration by a significant margin. This especially applies to us considering the water stress in our area of operation.” -Excerpt 40-

These success stories represent a wider trend: the environmental positive impact of digital transformation is the most evident when digital technologies are incorporated in the already existing sustainability infrastructure, renewable energy systems, water recycling facilities, waste management programs and not implemented separately. Digital transformation enhances the environmental performance of the physical sustainability investments and streamlines the utilization of the investments in real time.

4.4.2 Theme 02: Risks and Challenges of Digital Transformation for Environmental Sustainability

Though the environmental advantages of digital transformation are enormous, the respondents of both companies also listed various risks and problems that should be addressed attentively to make sure that the process of achieving digital transformation does not create any unintentional environmental costs or jeopardize the general sustainability objectives. These risks are of financial, technical, human and environmental

nature and their recognition indicates an intellectual sophistication of digital transformation that is not blind enthusiasm.

Initial Investment Costs and the Risk of Sustainability Trade-offs

The greatest challenge that was mentioned by most respondents was the high initial cost of rolling out extensive digital transformation initiatives. Although this is more of a financial issue, it also has significant environmental sustainability implications: companies that are not in a position to afford the financial commitment needed to fully digitally integrate may develop partial or piecemeal digital systems that achieve less than optimal environmental returns, or may invest less in environmental uses of digital technology than in more directly financially visible operational gains.

Respondent 02 – Company 01

“Digital transformation requires a big initial investment. We have to spend it on hardware, software, integration, training, and ongoing maintenance. At the beginning, it was hard to justify these costs based on environmental benefits. So, we had to focus on operational efficiency first and present the environmental benefits as a bonus. Because of this, smaller firms in our industry might struggle with the financial side. That can stop them from gaining the same environmental benefits that we’ve been able to achieve.”-Excerpt 41-

Respondent 05 – Company 02

“We identified an early risk. If not planned well, digital transformation could lead to too much spending on technology infrastructure. This could reduce investment in important sustainability areas like renewable energy, water recycling, and other physical assets. To avoid this, we were deliberate in our approach. We made sure our digital transformation roadmap and sustainability investment plan were developed together. This helped prevent them from competing for the same budget.” -Excerpt 42-

E-waste and the Environmental Cost of Digital Infrastructure

Another risk that was given significant consideration by respondents with environmental awareness was the environmental impact of digital infrastructure as such, including the generation of electronic waste (e-waste) during hardware replacement, and the energy usage of data centers, servers, and networked devices. This risk is especially relevant given the volume of IoT sensors, computing devices, and network equipment needed to achieve the type of comprehensive digital transformation that the two firms have outlined.

Respondent 03 – Company 01

“We’re very aware that using lots of IoT sensors, upgrading computing systems, and replacing old technology can create environmental problems too, especially in the form of e-waste. If this isn’t managed properly, the environmental impact of your digital systems can cancel out some of the benefits they’re supposed to create. To deal with this, we’ve put a formal e-waste management policy in place. This includes working with certified recyclers to make sure hardware is disposed of responsibly.”-Excerpt 43-

Respondent 04 – Company 02

“We also take care in terms of energy consumption of our digital systems, such as a server, sensors, networking infrastructure, and cloud services. To cope with this, we have consciously decided to use cloud services, which are renewable energy as much as we can. We also make sure our on-site systems meet energy efficiency standards. The concept is quite straightforward: digital transformation must not produce new carbon emissions when we seek to cut the existing ones.” -Excerpt 44-

Skills and Capability Gaps

Both companies acknowledged the presence of human capabilities gaps as a major challenge during the first phases of digital transformation, directly affecting the environmental sustainability outcomes. Whether digital systems can generate environmental value or not rests on whether the operational staff can extract environmental data, respond

to digital alerts accordingly, and interact with digital tools that focus on sustainability. In case of lack or insufficient development of these capabilities, advanced digital environmental monitoring systems can produce data that is not successfully implemented, which restricts their practical effect on the environment.

Respondent 01 – Company 01

“During our initial digital transformation, an internal capacity to actually utilize these systems effectively towards environmental objectives was one of the largest challenges. Our production teams had to be trained to interpret the data, such as energy use and waste, to make actual changes to operations, and that technology was available. And without that human ability, even the most advanced digital systems will not give you the results that you are striving to achieve in your environment.”-Excerpt 45-

Data Security and Environmental Compliance Risks

Another risk that was mentioned by the respondents and had certain environmental sustainability implications was data security. Data on environmental performance such as the emissions records, waste generation, and sustainability of the supply chain, are now being regulatorily disclosed and externally audited. The integrity of environmental performance records will be compromised during a data security breach and may put the firms in regulatory fines, reputational loss and loss of stakeholder trust that dilutes their overall sustainability.

Respondent 06 – Company 02

“Our environmental performance data is becoming more and more a part of our regulatory compliance and stakeholder reporting requirements. An IT issue of a security breach to corrupt or expose this data would not simply be an IT issue, it would be an environmental governance issue with possible regulatory and reputational implications. That is why we consider cybersecurity as a component of our digital sustainability plan, and not an IT issue.” -Excerpt 46-

4.4.3 Theme 03: Mitigation Strategies for Responsible and Environmentally Sustainable Digital Practices

To address the above identified risks and challenges, both companies have come up with conscious mitigation measures that will make sure that their digital transformation initiatives are not only consistent with their environmental sustainability objectives but also proactive to them. These approaches are indicative of a very advanced insight that responsible digital transformation means continuous consideration of the environmental impact of the technology adoption process as opposed to the environmental good that it produces.

Respondent 02 – Company 01

“First, we roll out one step at a time so that we do not run huge financial risks at once. Second, we maintain our hardware in a good condition and extend its use, reuse where we can, and dispose of it in a responsible manner to cut down e-waste. Third, we continue to develop the skills of our team to be able to actually utilize these digital tools in order to generate real environmental benefits. This is not something that we consider after, it is something that is embedded in the way we approach our digital transformation.”-Excerpt 47-

Respondent 05 – Company 02

“Our responsible digital practices policy has been created to specifically consider the green aspects of our technology business. These involve hardware energy efficiency norms, e-waste disposal guidelines, renewable energy mandate of our digital infrastructure and data governance norms, which safeguard the integrity of our environmental performance record. This policy is regularly reviewed every year to make sure that it is up to date with our changing digital world.”-Excerpt 48-

The two businesses highlighted the need to consider the environmental sustainability factor directly into their digital transformation governance models - making sure that their decisions to invest in technology are considered not only through operational and

financial parameters but also through their effect on the environment. Such a combined approach helps avoid the separation of sustainability and technology agendas that might otherwise lead to digital transformation programs that would bring operational benefits at the expense of the environment.

4.4.4 Theme 04: Future Plans for Digital Transformation and Environmental Sustainability

In perspective, Company 01 and Company 02 expressed ambitious and sustainability-focused future plans of further integration of digital transformation and sustainability, and they are the plans that indicate the intention to further develop the interrelationship between technological capacity and environmental responsibility that define their present operations.

Respondent 01 – Company 01

“Digital transformation will be the focus of our future strategies, with a certain target date by which we will be carbon neutral in our manufacturing processes. Our intention is to monitor our real-time emissions throughout its entire supply chain, incorporate AI-based carbon optimization into our production planning, and digital platforms to engage our suppliers more systematically in their own decarbonization initiatives. We view digital transformation and environmental sustainability as one and the same approach in the future.” -Excerpt 49-

Respondent 06 – Company 02

“We are actively considering the use of blockchain technology in supply chain traceability. This would provide us with a far more insight into the environmental impact of all ingredients and materials we are using. Meanwhile, we are testing superior AI systems with the capacity to streamline the whole production process, rather than individual components, to have a lesser effect on the environment. We intend to develop a completely digitized and sustainable manufacturing facility that will be a benchmark in the industry in Sri Lanka.” -Excerpt 50-

These proactive statements unveil companies that do not only react to the pressure of environmental sustainability activities in a reactive manner but also are initiating their digital transformation journeys based on long-term environmental objectives. A desire to be carbon neutral and to develop circular economy solutions and use new technologies (blockchain) to ensure supply chain environmental responsibility is a degree of strategic integration of digital transformation and environmental sustainability that makes these firms true leaders in the Sri Lankan manufacturing industry.

The results of this third sub-objective thus confirm the fact that the relationship between digital transformation and environmental sustainability in these top biscuit production companies is not only incidental but also unidirectional. Digital transformation yields enormous environmental impacts such as energy efficiency, waste reduction, supply chain visibility, and environmental reporting as well as posing risks, which must be managed deliberately. The companies that manage to navigate this complexity the best are those who do not see digital transformation and environmental sustainability as two parallel initiatives but as one seamless strategic initiative, one that is measured rigorously, governed responsibly and constantly developed to respond to new technological opportunities and environmental demands.

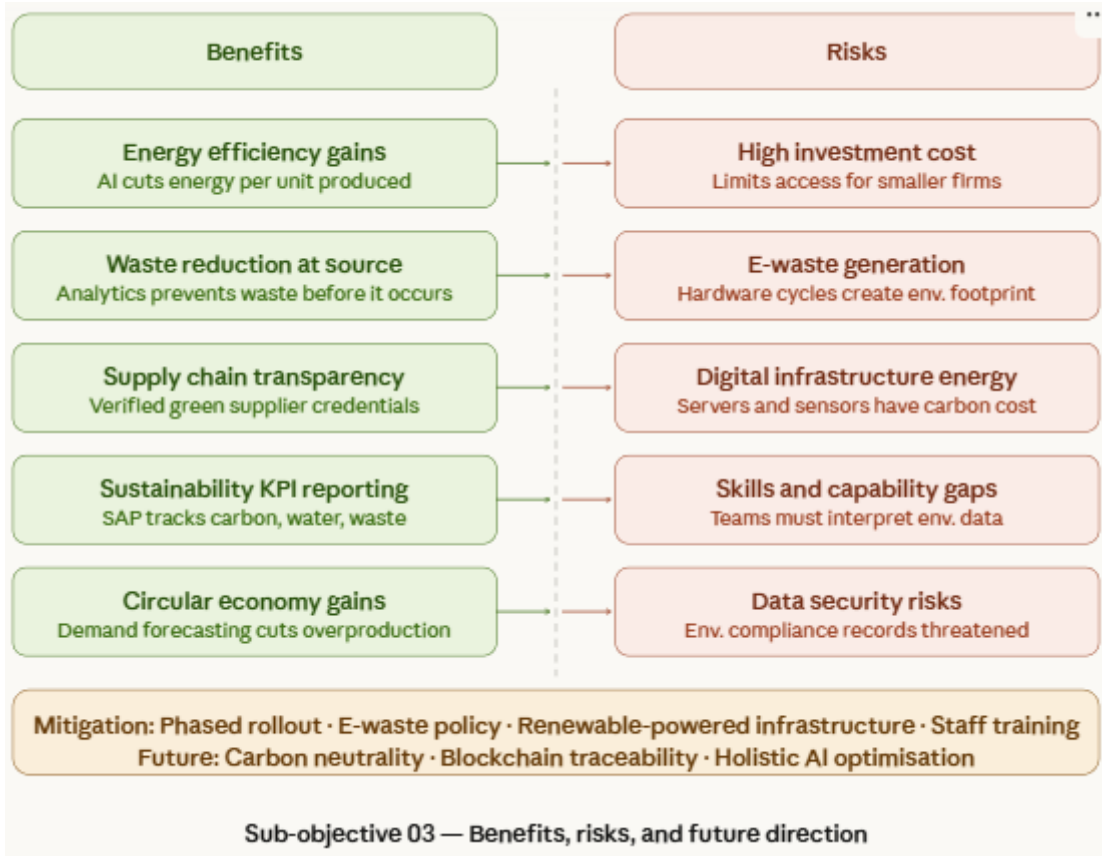


Figure 4. Summary of sub objective 03: Benefits, Risks and future direction (Author’s own work).

Table 7. Summary Table for Perceived benefits and risks associated with digital transformation for sustainability practices.

Theme	Meaning	Evidence
Benefits of Digital Transformation for Environmental Sustainability	If there are some challenges during the digital transformation period, after the transformation there are more advantages that benefited for the operations and whole business process. It’s not negatively	“Digital transformation has yielded one of the greatest advantages to us in the form of a reduction in our energy consumption. Through tracking our production line in real time, we realized that there were various areas where we were wasting energy and machines left running when they’re not being used, poor oven temperature controls and we dealt with these systematically. Since we installed these

	<p>affecting the sustainability practices also. This theme explores the potential benefits that sustainability practices from digital transformation.</p>	<p>digital systems our energy consumption per unit of production has significantly decreased.</p> <p>Respondent 01 – Company 01</p> <p>“Our carbon footprint reduction strategy has focused on digital transformation. With the optimization of the processes through AI, we have managed to make our baking activities much energy intensive. The system continually regulates parameters in accordance with real-time information, and the energy efficiency of the system is possible in a way that would be impossible under manual control.”</p> <p>Respondent 05 – Company 02</p> <p>“Prior to the digital transformation, we were producing an immense amount of waste during production that we could hardly justify or avoid. Since the adoption of our data analytics systems, we have been in a position to track the waste to the process variables and rectify them at the source. Our batch waste has been minimized significantly, and this is of benefit to the environment and the cost.”</p> <p>Respondent 03 – Company 01</p> <p>"Our analytics systems and MES have provided us with a far more accurate understanding of waste production points of our production</p>
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		<p>process. We now conduct regular waste reduction reviews using real data as opposed to estimates and as such, we have been able to establish and accomplish more ambitious waste reduction targets."</p> <p>Respondent 04 – Company 02</p> <p>“Through our digital supply chain platform, we are now able to trace our raw materials back to its source and ensure our suppliers are living up to our environmental standards. This has enabled us to make better sourcing choices and to collaborate with suppliers to enhance their environmental activities, which, when our supply chain information was in pieces, was merely not possible as it was then manual.”</p> <p>Respondent 02 – Company 01</p> <p>“Digitization of the supply chain has turned around our sustainability agenda. Now we are able to trace the carbon intensity of our sourcing of ingredients, to trace certifications of the packaging materials and to assess the environmental performance of suppliers in a systematic way. This provides the information to make truly sustainable sourcing choices as opposed to self-reported information by suppliers.”</p> <p>Respondent 06 – Company 02</p>
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		<p>“We have digital systems that have revolutionized our capacity to report on environmental performance. Now we are able to compile detailed reports on our carbon emissions, our energy usage, our water usage and our waste generation at any given point in time, in terms of our production line, product category or time period. Such reporting was something that was unthinkable in the pre-digital transformation era and it has rendered our sustainability commitments much more believable and realistic.”</p> <p>Respondent 05 – Company 02</p> <p>“Among the success stories, I would mention our solar power plant combined with our digital energy management system. Prior to the digital revolution, despite the installation of the solar panels, we were not maximizing our energy consumption patterns to match the solar generation peaks. After we incorporated the digital energy management system, we were able to dynamically adjust energy intensive production to the peak solar generation times which maximized our utilization of renewable energy and further minimized our dependence on grid power. This integration has also saved a lot of carbon.”</p> <p>Respondent 01 – Company 01</p>
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		<p>“One of the positive changes that I would mention is our reduction of water consumption. By operating in real time on the amount of water used in our cleaning and processing processes, and by optimizing our water recycling systems using AI, we managed to cut the amount of freshwater consumed within the initial year of complete digital integration by a significant margin. This especially applies to us considering the water stress in our area of operation.”</p> <p>Respondent 06 – Company 02</p>
<p>Risks and Challenges of Digital Transformation for Environmental Sustainability</p>	<p>While this is a new concept for the organization as well as the employees, companies had to face some kinds of risks. Because of these risks other companies in the industry are reluctant to adapt to this change. This theme explains such kinds of risks.</p>	<p>“Digital transformation requires a big initial investment. You have to spend on hardware, software, integration, training, and ongoing maintenance. At the beginning, it was hard to justify these costs just based on environmental benefits. So, we had to focus on operational efficiency first and present the environmental benefits as an added bonus. Because of this, smaller firms in our industry might struggle with the financial side. That can stop them from gaining the same environmental benefits that we’ve been able to achieve.”-</p> <p>Respondent 02 – Company 01</p> <p>“We identified an early risk. If not planned well, digital transformation could lead to too</p>

		<p>much spending on technology infrastructure. This could reduce investment in important sustainability areas like renewable energy, water recycling, and other physical assets. To avoid this, we were deliberate in our approach. We made sure our digital transformation roadmap and sustainability investment plan were developed together. This helped prevent them from competing for the same budget.”</p> <p>Respondent 05 – Company 02</p> <p>“We’re very aware that using lots of IoT sensors, upgrading computing systems, and replacing old technology can create environmental problems too, especially in the form of e-waste. If this isn’t managed properly, the environmental impact of your digital systems can actually cancel out some of the benefits they’re supposed to create. To deal with this, we’ve put a formal e-waste management policy in place. This includes working with certified recyclers to make sure hardware is disposed of responsibly.”</p> <p>Respondent 03 – Company 01</p> <p>“We also take care in terms of energy consumption of our digital systems, such as a server, sensors, networking infrastructure, and cloud services. To cope with this, we have</p>
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		<p>consciously decided to use cloud services, which are renewable energy as much as we can. We also make sure our on-site systems meet energy efficiency standards. The concept is quite straightforward: digital transformation must not produce new carbon emissions when we seek to cut the existing ones.”</p> <p>Respondent 04 – Company 02</p> <p>“During our initial digital transformation, an internal capacity to actually utilize these systems effectively towards environmental objectives was one of the largest challenges. Our production teams had to be trained to interpret the data, such as energy use and waste to make actual changes to operations, and that technology was available. And without that human ability, even the most advanced digital systems will not give you the results that you are striving to achieve in your environment.”</p> <p>Respondent 01 – Company 01</p> <p>“Our environmental performance data is becoming more a part of our regulatory compliance and stakeholder reporting requirements. An IT issue of a security breach to corrupt or expose this data would not simply be an IT issue, it would be an environmental governance issue with possible regulatory and reputational implications. That is why we consider</p>
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		<p>cybersecurity as a component of our digital sustainability plan, and not an IT issue."</p> <p>Respondent 06 – Company 02</p>
<p>Mitigation Strategies for Responsible and Environmentally Sustainable Digital Practices</p>	<p>Digital Transformation is a very supportive adaptation for the overall business process in every organization. But many companies are not very aware of that, and they are reluctant to adapt to this within their organizations due to above-mentioned risks. This theme explains the strategies that are used by both relevant companies to mitigate those risks.</p>	<p>"First, we roll out one step at a time so that we do not run huge financial risks at once. Second, we maintain our hardware in a good condition and extend its use, reuse where we can, and dispose of it in a responsible manner to cut down e-waste. Third, we continue to develop the skills of our team to be able to actually utilize these digital tools in order to generate real environmental benefits. This is not something that we consider after, it is something that is embedded in the way we approach our digital transformation."</p> <p>Respondent 02 – Company 01</p> <p>"Our responsible digital practices policy has been created to specifically consider the green aspects of our technology business. These involve hardware energy efficiency norms, e-waste disposal guidelines, renewable energy mandate of our digital infrastructure and data governance norms, which safeguard the integrity of our environmental performance record. This policy is regularly reviewed every year to make sure that it is up to date with our changing digital world."</p> <p>Respondent 05 – Company 02</p>

<p>Future Plans for Digital Transformation and Environmental Sustainability</p>	<p>This theme is about how organizations plan to use new digital tools to work better while also protecting the environment.</p>	<p>“Digital transformation will be the focus of our future strategies, with a certain target date by which we will be carbon neutral in our manufacturing processes. Our intention is to monitor our real-time emissions throughout its entire supply chain, incorporate AI-based carbon optimization into our production planning, and digital platforms to engage our suppliers more systematically in their own decarbonization initiatives. We view digital transformation and environmental sustainability as one and the same approach in the future.”</p> <p>Respondent 01 – Company 01</p> <p>“We are actively considering the use of blockchain technology in supply chain traceability. This would provide us with a far more insight into the environmental impact of all ingredients and materials we are using. Meanwhile, we are testing superior AI systems with the capacity to streamline the whole production process, rather than individual components, to have a lesser effect on the environment. We intend to develop a completely digitized and sustainable manufacturing facility that will be a benchmark in the industry in Sri Lanka.”</p> <p>Respondent 06 – Company 02</p>
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5 Conclusion

5.1 Chapter Introduction

This study examined the effects of digital transformation on the environmental sustainability practices in the top biscuit manufacturing companies in Sri Lanka. The research involved two of the most successful producers of biscuits in the country and collected information based on the in-depth interviews with the key employees of these two organizations. The results are structured in the three sub-objectives of the research and end with a literal response to the main research question.

5.2 Summary of Key Findings

5.2.1 Findings from Sub-Objective One: Current Level of Digital Transformation

The initial sub-objective was to comprehend to what extent these companies have already gone in their implementation and integration of digital technologies into their work. The results demonstrate that the two companies have already achieved a lot in their digital transformations paths and are utilizing a variety of sophisticated technologies.

Enterprise Resource Planning systems are used by both companies in managing their business processes. Company 02 was also the first company in Sri Lanka to implement SAP S/4HANA, one of the latest ERP systems available globally. This adoption indicates how keen the company has been on ensuring that it remains ahead of technology. Both companies also employ the use of Manufacturing Execution Systems to monitor and control their production processes in real time thereby helping them reduce downtime, minimize waste and enhance the overall production efficiency.

In addition to ERP and MES, the two companies have implemented sensors on the Industrial Internet of Things, which are linked to their machinery and equipment. These sensors can provide real-time information about their energy consumption, machine

output, and the state of production, providing managers with a live perspective of what is occurring on the factory floor at any time. Artificial intelligence and sophisticated data analytics are also being utilized, and both companies are using those technologies to not only handle the large amounts of data these systems produce but also convert that data into actionable information to make important decisions. The cloud computing systems (and Microsoft Azure used by Company 01) enable both firms to store and retrieve data centrally and share it with various departments throughout the business.

Both companies have heavily integrated automation in their manufacturing processes, which has minimized human error, enhanced consistency, and most importantly, minimized wastage of energy and materials. Both firms also rely on business analytics, including Power BI, to visualize performance data and disseminate insights throughout their organizations and enable decision-makers across levels to see environmental and operational performance.

The fact that these findings are not only about the spectrum of technologies implemented but also the extent to which they are embedded in the daily activities is of particular importance. Such technologies do not work alone. Their collaboration instead is of an interconnected ecosystem which provides both companies with a holistic, real-time view of their activities - including their environmental performance. Such integration is a sharp contrast to the pre-digital period when the data about the environment was gathered manually, examined every now and then, and responded to gradually.

5.2.2 Findings from Sub-Objective Two: Environmental Sustainability Practices

The second sub-objective aimed to find out what environmental sustainability practices these firms have implemented and how digital transformation has influenced such practices. The results show that the two companies are striving towards environmental sustainability in five major areas.

Company 01 has installed a solar power plant in its manufacturing plant generating clean renewable energy to operate its manufacturing facility in terms of energy and carbon management. Both companies have invested in energy efficient production equipment

such as high efficiency ovens, heat recovery systems which recapture and re-use thermal energy used in the baking process. The strength of these physical investments is that both businesses have linked them to digital energy management systems that track consumption both in real-time and dynamically optimize energy consumption. This implies that the environmental value of solar installation, say, is proactively optimized by digital systems, which match the energy-intensive production processes with maximum solar output.

Both companies have put in place steps towards minimizing their freshwater usage on water conservation. Company 01 has installed rainwater harvesting and has implemented a closed-loop water recycling system in its cleaning and processing facility, thus drastically decreasing its reliance on the water supply. Digital monitoring systems monitor water consumption in real-time, which allows identifying unusual consumption patterns promptly and handling them before they become critical.

In terms of waste minimization, both companies have shifted focus on waste management once generated into waste management and prevention at the very source. Waste is tracked with data analytics tools that can trace waste to certain process variables like specific equipment settings or ingredient batches and then production processes are adjusted to remove those root causes. Both companies also have recycling and composting schemes to take unavoidable waste off landfill, and both are striving towards the principles of the circular economy where materials are re-used or recovered instead of being discarded.

In packaging, both companies have replaced the traditional plastic packaging or polyethylene with biodegradable and recyclable substances. This move has a direct impact on downstream environmental effects of their products once they are out of the factory as they recognize that environmental responsibility does not just end at the production line but to the entire lifecycle of the product.

Lastly, digital platforms in the supply chain management have provided both businesses with a significantly increased insight into the origin of their raw materials, as well as the

operations of their suppliers. This traceability enables them to focus on suppliers that comply with their environmental policies, collaborate with suppliers to enhance their policies, and minimize the number of carbon footprints related to sourcing and logistics decisions.

Collectively, these results indicate that digital transformation has not merely brought an extra element of technological ability to these companies. It has radically transformed their environmental sustainability approach, making it more specific, more responsive, more measurable and more integrated into their core company business.

5.2.3 Findings from Sub-Objective Three: Benefits and Risks of Digital Transformation for Environmental Sustainability

The third sub-objective examined the perceived benefits and risks which the two companies connect with employing digital technologies to improve their environmental sustainability performance.

On the benefit side, the results are concise and consistent. Both corporations noted significant energy savings per unit of production as the direct effect of digital monitoring and process optimization with the help of AI. The production of waste has been reduced since digital systems can now detect the causes of waste and rectify them prior to compounding. The level of supply chain transparency has also been enhanced, which has resulted in better-informed and more environmentally friendly sourcing decisions. It has revolutionized environmental performance reporting in the sense that companies that used to rely on periodic estimates and manual records are now able to produce detailed and real time reports on their emissions of carbon, water and waste measurements at any given moment. This reporting feature enhances internal accountability and external credibility by the regulators and other stakeholders.

There were also some similar success stories that were common to both the companies, and they portray how digital transformation has a real-world environmental impact. One such initiative is the digital energy management that Company 01 has adopted with its solar power plant by balancing production with the peaks of solar generation. The

company has optimized its utilization of renewable energy and minimized its use of electricity generated by the grid. Company 02 also made substantial water savings through the integration of real-time water monitoring with AI-optimized recycling.

On the risk side, the conclusions are also open-minded. The initial investment in digital transformation is a real obstacle, especially in small companies that might not be able to afford large-scale investments. Both companies recognize that the business case of digital transformation can be most readily established based on operational efficiency, and that the benefits of environmental sustainability should be seen as secondary, an issue that can be detrimental to the priorities of environmental sustainability in companies with limited resources.

Replacement hardware cycles, and the energy used by the digital infrastructure itself (servers, sensors, and cloud computing services) were also found to be sources of electronic waste that needs to be actively managed. Both companies said that they were conscious of the fact that a digital transformation program aimed at making the environment less harmful could cause new environmental liabilities unless the footprint of the technology itself is taken into careful consideration.

A practical risk noted was the human capability gaps. There is no environmental data generated by digital systems beyond the interpretation and action of the people. When the companies were at the early stages of digital transformation, they had a problem with their internal capabilities to effectively utilize environmental data. There was also the increased risk of data security issues, especially concerning environmental compliance records, a breach of which not only has regulatory but also reputational implications.

These risks are being addressed by both firms by a mix of staged implementation plans, official e-waste disposal plans, choice of cloud infrastructure with renewable energy sources, cybersecurity strategies, and continuous employee education programs. Moving forward, both corporations have grand strategies which continue to connect digital transformation with environmental sustainability such as roadways to carbon neutrality,

usage of blockchain technology in supply chains to traceability, and creation of AI systems that can optimize their overall production workflows to the lowest environmental impact.

5.2.4 Answer to the Research Question

How does digital transformation impact environmental sustainability practices in biscuit manufacturing firms?

According to the results of this research, digital transformation plays an important and mostly a positive role in the environmental sustainability practices of biscuit manufacturing companies. Digital transformation and environmental sustainability are not two distinct strategic issues, but two ideas that go hand in hand with each other - without digital technologies, data, and operational infrastructure, it is impossible to manage environmental sustainability effectively.

In these firms, environmental sustainability was handled on a reactive basis, prior to the digital transformation. Monitoring energy and water usage was at a facility level with periodic reports, addressing waste was done post-generation, and supply chain environmental information was disaggregated and hard to act upon. There were environmental objectives, but they could not be precisely measured or systematically pursued.

This has been transformed by digital transformation. With the implementation of IIoT sensors, AI, MES systems, and cloud computing, as well as unified ERP systems, both organizations can now see real-time into all environmentally important areas of their operations. Energy use is also measured at the level of individual equipment and optimized. The causes of waste are followed down to their origin and minimized. There are better monitoring and recycling of water that is used. The supply chain sourcing is informed by authenticated environmental information. And the same rigor and frequency of reporting environmental performance exist as financial performance.

More to the point, physical sustainability investments are further enhanced by the effect of digital transformation. Solar panels, water recycling and waste management

infrastructure can all be much more effective when embedded in a digital ecosystem that can optimize the utilization of these types of infrastructure in real-time. This amplification effect implies that the environmental payoff on physical sustainability investment of digitally transformed firms is significantly greater than that of digitally disintegrated firms operating these assets.

Meanwhile, the analysis also confirms that digital transformation is not a risk-free journey towards environmental sustainability. Digital infrastructure costs, both in energy usage, hardware waste, and financial investment should be proactively controlled so that the environmental benefits of transformation outnumber the environmental costs of transformation. Companies that embark on digital transformation in a strategic manner, by including environmental concerns in their technology governance at the very core are those that can achieve the full potential of digital transformation as it relates to the environment.

To sum up, an example of the most effective tools that biscuit manufacturing companies can utilize to enhance their environmental sustainability performance is digital transformation, planned and implemented responsibly. It helps such companies to transform their aspirations into accountability - making the environmental promises into the quantifiable, manageable, and ever-better realities of operation.

5.3 Theoretical Contribution

The research makes a valuable contribution to academic knowledge in several ways as it analyzes the influence of digital transformation on environmental sustainability practices in the context of biscuit manufacturing in Sri Lanka - a location that has received very little attention in existing research.

The first contribution is conceptualizations of digital transformation itself. The definition of digital transformation presented by Gong and Ribiere (2025) as an organizational change aimed at recreating business models via the use of digital technologies assumes the main definition of digital transformation as a process based on creating economic

and operational value. This paper builds upon this definition by showing that the value created by digital transformation is also essentially environmental. Digital technologies are not merely making the business more efficient when they are profoundly integrated into the operations of an organization; they transform it into a more responsible entity for the environment. The creation of this environmental sustainability aspect in the digital transformation theory fills the gap in the literature on the topic of food manufacturing that has not been explicitly addressed and extends the theoretical framework of digital transformation as a theoretical construct beyond its economic-focused operationalization.

The second contribution is associated with the relationship between digital technologies and environmental sustainability in the developing economies. Artificial intelligence, big data, cloud computing, and the Internet of Things are some of the drivers of digital transformation as defined by scholars like Mohamed Hashim et al. (2022) across the world. But the bulk of empirical studies which support this assertion have been carried out within the context of developed countries. This paper has presented evidence on Sri Lanka, a developing economy, to indicate that these same technologies are proactively being applied to achieve environmental sustainability objectives in the food manufacturing sector. This proves that the correlation of technology-sustainability relationships as found in the international literature does not only exist in the developed and technologically competent countries but is also emerging in the emerging markets context.

The third contribution is the discovery of what this paper terms a digital sustainability amplification effect. The results indicate that physical environmental investments like solar power plants, water recycling systems and waste management infrastructure provide significantly more benefits to the environment when linked and operated with digital systems. A solar panel will decrease carbon emissions itself. A digital energy management system and a solar panel that schedules production based on the time of maximum production reduces carbon emissions by a much greater percentage. The principle of this amplification, whereby the physical sustainability assets are multiplied with the

aid of digital technology, is a valuable theoretical lesson that has not been completely expressed in the current food manufacturing or sustainability literature.

The fourth contribution is to the new literature on the risks of digital transformation in terms of sustainability. Most of the current studies about digital transformation risk concentrate on the financial, competition, or cybersecurity aspects. This paper has pointed out that there are environmental risks associated with digital transformation as well, such as carbon footprint of digital infrastructure, electronic waste production, and the risks of data integrity related to environmental compliance records. By emerging and normalizing these dimensions of environmental risks, the study expands the current body of risk literature in a direction relevant especially to sustainability-oriented digital transformation initiatives.

Lastly, the research contributes to methodology by showing that qualitative, interview-based research is highly appropriate to reveal the lived experience of digital transformation and sustainability integration in a manner that could not be achieved through surveys and quantitative data. The richness of understanding created in this method, especially in terms of transformation towards proactive environmental management and enhancement of physical sustainability investments with the help of digital interconnection, validates the usefulness of qualitative inquiry in this field of study.

5.4 Managerial Implications

There are several practical implications of the findings of this study to managers and decision-makers at biscuit manufacturing companies and the food manufacturing industry, in general. It is hoped that these implications can assist managers to make more informed choices on how to go about digital transformation in a manner that can contribute to the achievement of environmental sustainability objectives.

Digitization and environmental sustainability should be a single strategy and not two. The most significant lesson of this research is that the companies get the most beneficial impact on the environment when they formulate their digital transformation and

sustainability strategies in pairs rather than in isolation. At the stage of the digital transformation roadmap, managers must make sure that environmental objectives, like carbon reduction, water use reduction, or waste reduction, are incorporated into the plan from the very beginning. In the process of making digital investment decisions, the environmental criteria must be included in the decision-making process in addition to financial and operational ones. This integration will not allow an instance where digital transformation enhances operational performance, and sustainability objectives are an afterthought.

Focus on real-time environmental monitoring as a basis. The switch to continuous, real-time digital monitoring as opposed to periodic and manual environmental monitoring was one of the most significant changes that both companies implemented. This change provides managers with direct insight into energy consumption, water consumption and waste production; thus, it is possible to identify issues early and react to them before they become critical. Managers who have yet to invest in it need to consider it a steppingstone, since most other environmental sustainability enhancements require the availability of this information in real time.

link physical sustainability investments to digital. Solar power stations, water purification plants, and garbage disposal devices are already physical sustainability investments made by many companies. The results of the current research demonstrate that these investments provide significantly superior environmental outcomes when being related to digital monitoring and optimization systems. Physical and digital sustainability investments should not be considered as two different decisions by managers; they need to be planned and implemented simultaneously to have the biggest impact on the environment.

Consider investing in people rather than technology only. The proposed digital systems can provide the enhancement of the environment only in case the individuals who use the systems know how to analyze the data and what action should be taken. The gaps in human capabilities were established as a real issue in the initial phases of the digital transformation by both companies in this study. Managers need to invest in training and

development initiatives that create the skills to utilize environmental data at the organizational base levels-production floor managers to supply chain managers to top management. In the absence of this investment, advanced digital systems may turn out to be an unutilized data warehouse.

Manage the environmental footprint of digital infrastructure itself. Managers must understand that there are their own environmental costs associated with the digital systems they implement, such as the energy used by the servers, sensors, and cloud systems, and electronic waste when they change hardware. These expenses need to be kept an eye on and proactively controlled. Such practical measures as choosing cloud providers working with renewable energy, establishing energy efficiency policies in hardware acquisition, and creating official electronic waste disposal procedures with certified recyclers can be taken. These costs should not be overlooked otherwise there is a risk of ending up with a scenario where digital investments that are meant to lower the environmental impact are generating a new environmental liability.

Link digital data to establish and strive to achieve high environmental goals. With real time availability of environmental performance data via integrated digital systems, specific, measurable environmental targets and progress against them can be established and monitored with the same degree of rigor as is applied to financial targets. Managers can take advantage of this potential by setting some progressive environmental targets - such as medium and long-term targets to reduce carbon emissions, water use, and waste diversion - and checking progress on a regular basis as part of regular management reporting. This strategy converts environmental sustainability statements into a working science.

Expand digital sustainability to the supply chain. The results indicate that better supply chain visibility and traceability are some of the biggest environmental benefits of digital transformation. Managers are not only encouraged to use digital platforms to track the environmental performance of their own operations but also to assess and involve their suppliers. Establishing environmental requirements of suppliers, exchanging information to facilitate common improvement efforts, and implementing digital traceability

solutions to check environmental assertions across the entire supply chain can greatly lower the overall environmental footprint of the business.

Phased implementation of the plans to control financial risk. The initial cost of digital transformation is a real barrier, especially in the case of smaller companies. Managers are advised to take a staged approach - investing in those projects that will yield the most obvious environmental and operational returns and the efficiency gains and cost savings of initial investments to finance the next steps. This will result in digital transformation being cost-efficient but still have a momentum moving towards the long-term targets of environmental sustainability.

5.5 Suggestions for Future Research

Although the current study has yielded important conclusions, it also indicates that there are a variety of gaps that the bodies of knowledge regarding the relationship between digital transformation and environmental sustainability in manufacturing need to be elaborated and enriched.

Future studies ought to be able to quantitatively test the results of this study on a larger scale. Since this research was qualitative and carried out in two companies, the results provide a depth and understanding but are not generalizable to the entire industry statistically. Extensive survey research involving the study of the correlation between the measures of digital technology adoption and the environmental performance results in a broader sample of biscuit and food manufacturing companies in Sri Lanka would be supplementary to the current results and offer a more solid foundation on the generalization. A more rigorous statistical framework can also be used to test certain propositions that arise out of this research such as the digital sustainability amplification effect.

Longitudinal research would be especially useful. The current study presents a picture of two companies in a single instance. A longitudinal study that follows the same firms across multiple years (measuring their environmental performance before, during and after major investments in digital transformation) would be much more evidence-based

regarding whether digital transformation does lead to improvements in environmental sustainability or other forces are at play. It would also illuminate the time lag between investment in digital and realization of various environmental benefits, which would be very valuable information to managers making investment decisions.

The experience of smaller and medium-sized firms in the biscuit and food manufacturing industry should also be studied in future research. The two firms in this research are two of the biggest and best endowed firms in the Sri Lankan market. The financial, technical, and human resource constraints are much more different in smaller firms, and their encounter with digital transformation and the environmental impact of the digital process might be much different. A study that is narrowed down to smaller companies would assist in coming up with more comprehensive recommendations and policies aimed at assisting the entire sector and not just the biggest companies.

Specific emerging technologies should be the focus of investigation in terms of their contribution to environmental sustainability. Blockchain-based supply chain traceability and holistic AI-driven production optimization were both recognized by both companies in this study as key directions in the future, yet at this point there is a gross lack of empirical studies into how these technologies perform in a food manufacturing sustainability setting. Further research on the real applications of these technologies and its environmental and practical effects and the organizational circumstances that make them successful would be a welcome addition to the knowledge base as well as management practice.

A comparative study of various countries would assist in defining to what extent what this research discovered is unique to Sri Lanka and to what extent it is general. The degree of digital infrastructure development, strictness of environmental standards, consumer awareness of the environment, and access to digital talent are all considerably different in various countries, and they can influence the nature of the relationship between digital transformation and environmental sustainability differently. Such comparative analysis among developing economies in South Asia, Southeast Asia, and others

would assist in charting out these differences and which results are universal, and which are context specific.

Lastly, future studies must include the views of more stakeholders such as suppliers, customers, regulators as well as environmental organizations. The current research is solely based on the views of internal company staff. Outside observers might hold a much different opinion of the effectiveness with which these companies are leveraging digital transformation to promote environmental sustainability and including such opinions would yield a more comprehensive and balanced analysis of the topic.

5.6 Limitations

This research was done with the clearly known limitations that need to be taken into consideration when reading and using the results of the research.

The number of companies studied is the most crucial limitation. The study is narrowed down to only two biscuit production companies, both companies being the most developed and resource endowed companies in the Sri Lankan market. Even though the intensive study of these firms has yielded deep and comprehensive information, their experience cannot be used to generalize what other firms in the industry are going through. Companies that are smaller, less digitally advanced, or lower budgeted, might have very different challenges and attain very different outcomes. This research must thus be interpreted as the generation of ideas, insights, and propositions and not a conclusion that is applicable across the industry.

The research is based on the companies themselves giving information in the form of interviews. This leaves the potential that respondents reported on the digital and sustainability practices of their firms in a more positive manner than the actual situation may deserve to be - a bias referred to as social desirability bias. Although the interviewing procedure was constructed in a way that stimulated truthful and narrow responses and, even though interviewing more than one individual, in each company allowed a certain degree of cross-checking what was stated, there could have been an

overemphasis on certain sustainability accomplishments and underemphasis on certain issues. The availability of independently checked environmental performance indicators, including audited sustainability reports or regulatory compliance documents would have given a more objective foundation to assessing the claims of the firms, but was not accessible in the context of this study.

The study captures a point in time. The digital transformation landscape as well as the environmental sustainability practices of these firms is changing rapidly. In technologies that were at early implementation during the data collection period (i.e. planned blockchain traceability systems or advanced AI optimization platforms), there were no actual environmental outcomes in the real world that could be measured. The results are thus an indication of the practices of these firms at a given time and might not necessarily give a complete picture of where they are today and where they will be in the future.

The geographical range of the study is the Sri Lankan setting, and it implies that the results could not be easily translated to the other countries. The regulatory environment, the conditions of the infrastructure, energy mix, labor market features, and cultural aspects in Sri Lanka have their own unique aspects that define the way the companies' approach both the digital transformation and environmental sustainability. These are not the same conditions as other developing economies and the results of Sri Lanka need to be relevant to other contexts with cautiousness and sensitivity to the local variations.

The thematic analysis method applied as a qualitative approach to the research is somewhat interpretive. Though the coding and analysis procedure was performed in a systematic and open-minded way, various scientists who will work with the same data of interviews could arrange the themes somehow differently or emphasize various aspects of the results. This is a characteristic of qualitative research and not a particular limitation of this research methodology, but it is crucial that readers are aware that the thematic structure provided here is one well-founded interpretation of the data and not the only possible interpretation of the data.

Lastly, the voices of external stakeholders like suppliers, customers, environmental regulators, or non-governmental organizations that address sustainability issues are not represented in this study. The image of digital transformation and environmental sustainability shown here is viewed solely through the perspective of individuals in the two companies. External stakeholders may have very divergent views on the effectiveness of environmental sustainability initiatives at these firms and the believability of their sustainability messages, or where they are most needed. It would be better to have such external voices in the upcoming studies so that the picture of the topic would be complete and more balanced.

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Appendices

Appendix 1. Interview Instrument

Research sub objectives	Interview Questions
<p>To assess the current level of digital transformation among biscuit manufacturing firms, focusing on the adoption and integration of digital technologies.</p>	<ol style="list-style-type: none"> 1. Can you tell me what are the digital technologies currently used in your Company? 2. How integrated are these digital technologies into your overall business operations? 3. Have you implemented any specific software or systems to enhance efficiency or productivity in your manufacturing process? 4. How do these digital technologies help to enhance the company's efficiency, productivity, and competitiveness when compared to the previous situation?
<p>To examine the environmental sustainability practices implemented by these firms.</p>	<ol style="list-style-type: none"> 5. What are the environmental sustainability practices currently used in your company? 6. Can you provide specific examples of initiatives or programs and explain how they relate to environmental sustainability? 7. As you think, what are the changes in environmental sustainability practices that used you before the digital transformation than now? 8. Can you share examples of how digital transformation has led to positive environmental impacts and explain how it affects the biscuit manufacturing industry?

<p>To identify the perceived benefits and risks of digital transformation in enhancing environmental sustainability within the biscuit manufacturing sector.</p>	<p>09. What are the challenges you faced in the initial stage of adopting the digital transformation?</p> <p>10. What are the potential risks associated with using digital technologies for environmental sustainability?</p> <p>11. How can biscuit manufacturing firms mitigate these risks and ensure responsible and environmentally sustainable digital practices?</p> <p>12. What are the benefits associated with integrating digital technologies for environmental sustainability?</p> <p>13. Can you share any success stories or positive outcomes related to your digital transformation efforts for environmental sustainability?</p> <p>14. What are your company's future plans for integrating digital transformation and environmental sustainability?</p> <p>15. How can digital transformation help biscuit manufacturing firms achieve their environmental sustainability goals?</p> <p>16. What are your company's strategies for addressing the potential negative impacts of digital transformation on environmental sustainability?</p> <p>17. Is there anything else you would like to add regarding digital transformation or environmental sustainability practices in your biscuit manufacturing firm?</p>
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Appendix 2. Declaration on the Use of Artificial Intelligence in the Study

The University of Vaasa encourages the use of artificial intelligence by students and teachers. The university policy states that a student should publicly declare whether artificial intelligence has been used to prepare his or her thesis. This statement should include what AI tools and language models were utilized, and why (University of Vaasa, 2023).

The AI tools made the following supportive tasks:

- Language and Grammar: ChatGPT GPT-4 model was used to detect and correct grammar, spelling, and sentence fluency in already written text.
- Formatting and Visualization: The AI helped me to facilitate the visual arrangement of the figures using my own input.

This paper has followed the guidelines and regulations used by the university with respect to usage of artificial intelligence as an instrument.