UNIVERSITY OF TECHNOLOGY SYDNEY

Assessing Triple Bottom Line Sustainability of Cotton Clothing Manufacturing – Advancing an Input-Output Production Analysis Methodology

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Thesis submitted in fulfilment of the requirements for the degree of

Master of Design (Research)

under the supervision of

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August 2024

Certificate of original authorship

I, Mia Zhou, declare that this thesis is submitted in fulfilment of the requirements for the award of the degree of Master of Design (Research), in the School of Design of the Faculty of Design, Architecture and Building at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

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Date: 20 August 2024

Note on the thesis format

This thesis was prepared to fulfil the criteria for Master by Research and is in the format of a conventional thesis. It adheres to the guidelines set forth in “Graduate Research Candidature Management, Thesis Preparation and Submission Procedures 2022 - University of Technology Sydney”. This thesis used the American Psychological Association (APA) 7^{th} edition referencing style. The tables and figures produced by the thesis author, Mia Zhou, are cited as "The Author" and constitute the vast majority.

Acknowledgement

I would like to express my heartfelt gratitude to the University of Technology Sydney for being an exceptional research hub and for holding amazing supervisors who have offered unparalleled support throughout my research journey. My principal supervisor, Associate Professor Timo Rissanen, granted me the freedom and valuable insights needed for innovation in my research, along with constant encouragement. I sincerely thank him for supporting me in both my research and personal matters. My supervisor, Associate Professor Maruf Chowdhury from UTS Business School, for his valuable insights, and my previous supervisor, Associate Professor Melissa Edwards, for guiding me to view my research from different perspectives, especially when shaping semi-structured interview questions.

I would like to express my gratitude to the chairs and panels of both the initial and final presentations for their valuable insights into my research: Associate Professors Zoe Sadokierski and Stefan Lie (chair), Associate Professors Maruf Chowdhury, Melissa Edwards (UNSW Business School), and Samantha Sharpe.

Thanks to the DAB HDR Director, Associate Professor Sumita Ghosh, former HDR Director, Associate Professor Toby Slade, the DAB HDR Support team, Georgina Donovan, Eva Garcia, Vanessa Setiadi, and the Graduate Research School for their support during my candidature.

This thesis also owes a debt of gratitude to the many practitioners I collaborated with over decades in the industry, whose experience greatly influenced this research. Special appreciation is given to Sandra Williams from CRDC/ CSIRO for her expertise on Australian cotton cultivation, and to practitioners whom I consider experts in the yarn-to-garment manufacturing process: Luo Tengfa, Wu Zhiping, Fang Jun, Fang Guoqing, Tang Xufeng, Jun Cai, Zhou Xianguo, among others.

Special thanks to the many wonderful HDRs I met at UTS. My deepest gratitude goes to my friend Biyanka (now a Dr. and Lecturer at UTS) for helping me navigate the unknowns at the start of my journey, rehearsing my presentations, providing invaluable feedback and encouragement, and looking after my son at times. Thanks to all the other incredible HDR friends like Bingyang, Kesty, Olivia, Samuel, Henry, Dong Kai, Mehrafarin, Megan, Abdullah, and Abdulrahman. Your companionship is greatly valued.

I also express my gratitude to my workplace, Southland Supply Group, for their unwavering support and flexibility in accommodating my research and parenting needs. Their understanding has been crucial in allowing me to balance my professional, academic, and personal commitments effectively. I am also grateful to my fantastic colleagues for fostering a supportive and joyful work environment.

I thank my parents for being proud of me on this research journey.

I extend my gratitude to the Australian Department of Education for the RTP scholarship and the NSW Department of Education for the scholarship top-up. Without this financial support, I am uncertain if I would have been able to continue this research.

I acknowledge that AI-powered language models, ChatGPT and IFLYTEK SparkDesk, assisted with grammar checking and paragraph editing based on the author's original writing, thereby enhancing the quality of this thesis composition.

Finally, I dedicate this thesis to my son, Joey Clark. His arrival inspired me to overcome domestic challenges and channel my enthusiasm and curiosity from my industry career into this research. He has been my source of strength, motivating me to persevere and strive for excellence.

Table of Contents

List of Figures

List of Tables

List of Acronyms

IDM	Industry Decision-making
IO	Input-Output
IOA	Input-Output Analysis
IOPMd	Input-Output Production Model
PEcMT	Production Economic Measures Table
PEM	Production Entrepreneurship Measures
PEnMT	Production Environmental Measures Table
PIODF	Production Input-Output Data Framework
PIOFs	Production Input-Output Flowcharts
PIOTs	Production Input-Output Tables
PSM	Production Social Measures
SMEs	Small to Medium-sized Enterprises
TBL	Triple Bottom Line
TBLPDs	Triple Bottom Line Production Datasets

ASSESSING TRIPLE BOTTOM LINE SUSTAINABILITY
OF COTTON CLOTHING MANUFACTURING:
Advancing an Input-Output Production Analysis Methodology

Mia Zhou

ABSTRACT

The fashion industry is facing significant environmental and social challenges, making sustainability a complex issue in the real world. Life Cycle Assessment (LCA) indicates that the production stage represents approximately 80% of the environmental impact of the industry; however, efforts for improvements from both academia and industry have focused on areas outside of production. While professionals recognize opportunities to enhance sustainability through improved practices, a limited comprehension of these practices and a lack of methodologies - highlighting literature gaps - constitutes a significant obstacle.

This study focuses on developing an Input-Output Production Analysis Methodology (IOPAM) designed to provide robust data that supports informed decision-making on enhancing production practices. Although the IOPAM is in progress, its ongoing refinement currently yield three key outcomes that benefit both industry and academia, including bridging existing gaps in the literature.

The first outcome involves achieving a crucial research objective by establishing a Production Input-Output Data Framework (PIODF) that streamlines data collection within the industry. The second outcome is the generation of practical insights related to cotton clothing production, which includes 28 Production Input-Output Flowcharts (PIOFs) mapping as many as 100 processes. These flowcharts illustrate how materials, machines, and labour contribute to products, along with their corresponding discharges. The third outcome, based on a theoretical case study of Australian cotton's global production impact, highlights data showing a substantial economic growth opportunity for the Australian cotton industry.

Keywords: Fashion, Clothing, Clothing Manufacturing, Input, Output, Production Process, Input-Output Production Analysis, Triple Bottom Line Sustainability, Australian Cotton

Chapter 1 Introduction

1.1 Background

The environmental and social issues within the fashion industry make achieving sustainability in this sector a significant real-world challenge. Fashion industry is estimated to be responsible for 8% (4-5 billion tonnes) of the global GHGs (Quantis 2018), 20% of global wastewater (United Nations Climate Change 2018), and 35% of oceanic primary microplastic pollution (190,000 tonnes). It consumes 79 trillion litres of water and produces 92 million tons of waste annually (Global Fashion Agenda and The Boston Consulting Group 2017).

At the same time, the sector's economic contribution is undeniable, especially in uplifting people from poverty (Fletcher and Tham 2019b). This industry contributes 3 trillion dollars to the global economy, corresponding to 2% of the world's Gross Domestic Product (GDP), and employs 3,384.1 million people (Fashion United, 2022). In Australia, according to the EY report (Ernst & Young Australia 2021), the fashion industry contributes $27.2 billion to the national economy in 2021 which count 1.5% of Australian GDP. This sector employs more than 489,000 Australians and 77% of them are female, which plays a significant role in providing the economic security of Australian women.

According to Life Cycle Assessment studies, the fashion industry's overall environmental impact is primarily driven by production, which accounts for up to 80% of the total impact. The remaining 20% is attributed to transportation, distribution, retail, use, and end-of-life processes (Sandin et al. 2019; Moazzem et al. 2021; Quantis 2018).

Sustainability advocates, including scholars and researchers, are actively pursuing solutions through various avenues such as design, consumption, and disposal (Payne 2020; McQuillan 2020; Rissanen 2013; Fletcher 2011; Gwilt 2011), technology, and business operations. Rissanen (2008) demonstrates that it is feasible to design garments without creating fabric waste. Fletcher (2011) argues that fashion users should be seen not just as consumers but also as contributors of ideas and skills to the fashion system, which can help them actively change or improvise their usage patterns. Gwilt (2011) emphasizes the importance for contemporary fashion designers to view sustainable strategies as opportunities for innovation. However, these efforts primarily focus on the impact of fashion retail, usage, and end-of-life, which fall under the LCA's 20% impact category. The production phase, which accounts for the remaining 80% of the impact, remains largely unexplored.

The industry's shift towards sustainability is evident through the adoption of technologies like 3D virtual sampling and blockchain, innovations in business models such as circular business models and clothing rental services, improvements in supply chain sustainability, corporate social responsibility (CSR) initiatives, and occasionally, environmental profit and loss accounting (e.g., PUMA's E P/L). Increasingly, leading fashion giants are making incremental progress towards using more sustainable materials and products. Apart from this, the majority of small to medium-sized enterprises (SMEs) in the fashion sector - comprising over 85% of the industry (Joze et al. 2023; Piller 2022) - as noted by Fletcher and Tham (2019a), recognize sustainability issues but take limited or no action, resulting in "*no net reduction*" (p.12) in the environmental impact.

The global community, however, is progressively calling on the sector to hasten advancements toward a sustainable industry, particularly concerning the management of environmental and social emergencies, as its current trajectory is clearly inadequate in meeting the SGD agenda 2030. Consequently, there is an immediate demand for research that focuses on production sustainability and can stimulate proactive initiatives within the industry aimed at achieving sustainable production, which necessitates identifying and addressing challenges from an industry viewpoint as discussed in the following section.

1.2 Challenge towards Sustainable Production and Research Question

Production refers to a series of processes for the creation and allocation of value. (Frisch 1964; Kurz, and Salvadori 1995) Witt clearly articulates it as "*the process of generating a specified outcome, i.e., a state or process with certain properties or, in economic terms, a certain 'output' by means of some 'inputs'*". (Witt 2003, p.2) This definition highlights the elements of production, including input, output, and the processes involved, while also indicating their economic context. Classic economics emphasizes that inputs are essential factors of production, typically classified into four main categories: land, labour, capital, and entrepreneurship. Outputs, on the other hand, are regarded as value-oriented products or services by "for-profit" businesses that engage production mainly to achieve economic gain. (Hinton 2020) With the global movement towards sustainable production, there is a growing demand to incorporate environmental and social factors alongside economic outcomes.

Consequently, the components of production can be interpreted to consist of inputs that correlate to land, labour, capital, and entrepreneurship, as well as outputs that cover economic, environmental, and social aspects, together with the processes that link these inputs to the outputs.

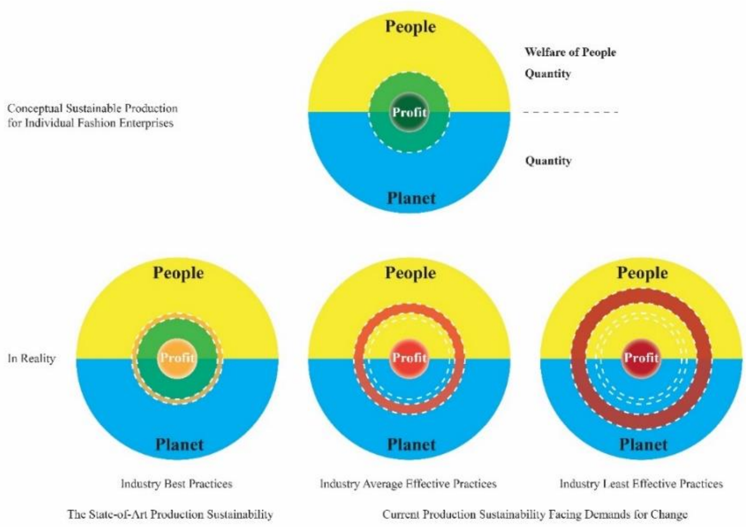
The fashion industry predominantly consists of for-profit organisations, and the undeniable reality is that their profit from production hinges on the allocation of resources and labour, which regrettably but inevitably leads to discharge. (Muthu 2020) Academics and researchers critique their profit-driven approaches that prioritize profit over environmental concerns, labour welfare, or a mixture of both, either directly or by influencing downstream processes, thus intensifying concerns related to sustainability challenges. (Hinton 2020; Fletcher and Tham 2019a) These criticisms, however, overlook the perspective of industry organizations. Firstly, profitability is not only vital but also a legal right for businesses (Hinton 2020). Secondly, essential insights regarding the incorporation of environmental and social factors into profit generation, without compromising the ongoing prosperity of the organization, at least to the degree of ensuring its survival, are absent.

This research is designed from the viewpoints of industry professionals, leveraging their experiences and insights that aim to integrate environmental and social considerations into production methods that safeguard profitability, thereby supporting industry decision-making (IDM) in the shift towards sustainable production alternatives. Practitioners frequently find that implementing advanced practices results in improved economic and environmental conditions, along with direct or indirect social advantages. In other words, different practices are linked to varying levels of resource use efficiency, product output quality and quantity, discharges including waste, and sustainable labour engagement, indicating their level of sustainability.

Logically, enhancing practices can result in greater sustainability. The challenge arises from the limited understanding of diverse practices, which reflects the literature gap noted in Chapter 2, section 2.3.2. This is further compounded by a lack of understanding regarding grassroots practices that could yield similar profits (product value after deducting tangible input costs) yet differ in their environmental and social impacts, thereby necessitating a thorough evaluation of production from the grassroots level. More specifically, there is a lack of understanding regarding production practices and the quantitative data linked to their tangible elements, such as the amount of product, resources, labour, discharges, and their corresponding value or cost, as well as the qualitative data that illustrates how quantity and value or cost are interconnected and associated with the overall impacts of production, including on human welfare. Empirically, these data can be retrieved or documented by individual organizations, allowing for analyses that reveal economic, environmental, or social prospects and facilitate the creation of solutions that assist in informed decision-making, thereby potentially driving change. When the data from different organizations is aggregated and analysed together, the operational approaches of each entity can be compared, identifying a spectrum of best practices, average effective practices, and less effective practices, which aids organizations, sectors, or industries in making informed choices as they transition to improved practices, ultimately enhancing sustainability in production. This approach of promoting change from the grassroots level to the decision-making tier is referred to as a bottom-up approach, in contrast to a top-down approach that change is formulated at the decision-making level and implemented at the grassroots level.

In theory, optimal practices lead to sustainable production by realizing profits with zero waste, balanced labour, and no excess emissions, without pressuring supply chains to adopt unsustainable methods. However, organizations may either deliberately or inadvertently protect their profits at the cost of sustainable impact by consuming more resources than required, unevenly distributing labour, and generating excessive discharge, or by shift their sustainability expenses to downstream suppliers. The degree of their sustainable impact varies with practices, ranging from minimal in best practices to significant in average and least effective ones, as illustrated in Figure 3.1.

Figure 3.1: Various Production Practices and the Degree of Production Sustainability



Source: The Author, Thesis Chapter 3, Section 3.1, p.44

The research tackles this lack of production knowledge that exists in both the industrial sector and academic literature, utilizing the author's extensive expertise of over 20 years in clothing production and her collaboration within the industry to conduct this comprehensive investigation into the detailed understanding of the quantitative and qualitative aspects of production components. The overarching aim of the research is to enable informed decision-making within industry to embrace more sustainable practices. The critical question is: "Which production data can be utilized, and how can it be applied to promote sustainable practices that will aid decision-making within the fashion industry?"

To adequately address this research question, the study is meticulously designed, resulting in well-defined research frameworks detailed in the following section and an extensive design process showcased in Chapter 3.

1.3 Research Frameworks

The research seeks to contribute to the sustainable advancement of production within the fashion industry. It is essential to establish a clear definition of production sustainability. Drawing on the Australian cotton industry's definition (Australian Cotton Industry’s Sustainability Working Group 2019), this study characterizes production sustainability as the capacity for production to operate profitably and efficiently while maintaining a balance with natural and human resources. It also means being accountable to stakeholders for the actions and impacts of the production process.

The fashion industry is a complex system composed of global networks of production actors across various value chains, including garments, footwear, trims and accessories, perfumes, and more (Buchel et al. 2022; Macchion et al. 2020), necessitating a strategic focus on cotton clothing production. It is anticipated that the insights gained, and experiences acquired through a comprehensive analysis of the sustainability of cotton clothing production can ultimately be applied throughout the broader fashion industry, all aim to enable informed decision-making within industry to embrace more sustainable practices.

Derived from the overarching aim of enhancing the sustainability of production by advocating for advanced practices within the cotton apparel sector, specific goals and objectives are established to guide actionable initiatives as follows:

Goal 1: establish complete TBL production datasets (TBLPDs) for individual organisations that effectively showcase practices while being capable of analytically identifying and monitoring areas of TBL sustainable opportunities, contributing to the development of proposals for decision-making on advanced practices. Achieving this goal requires two key objectives:

a) Designing a Production Input-Output Data Framework (PIODF)

b) Collecting data using the PIODF

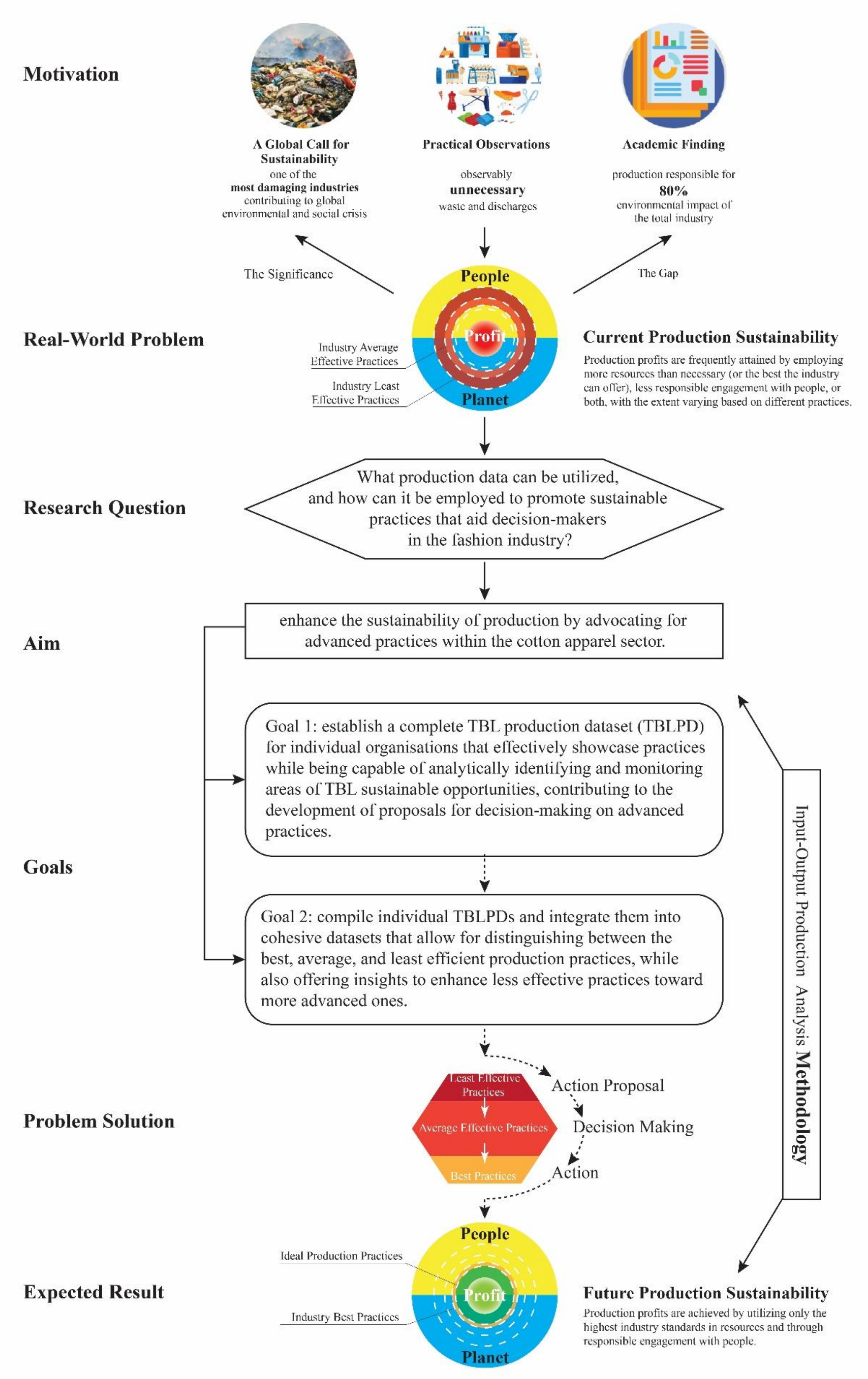
Goal 2: Compile individual TBLPDs and integrate them into cohesive datasets that allow for distinguishing between the best, average, and least efficient production practices, while also offering insights to enhance less effective practices toward more advanced ones.

The research scope (cotton clothing) and boundaries (production) clearly delineate the range of information and data collection and further refine the focus of the research. For example, in a specific organization within the cotton clothing sector, the information and data gathered should relate to a series of manufacturing processes that begin after design approval and end with the finished product stored in the warehouse (WH) before being distributed for marketing activities. In the context of the entire cotton clothing manufacturing from seeds to garments, there exist up to 100 processes across the entire production chain involving various organizations.

As mentioned earlier, the process serves as a crucial component of the production structure that links the two other elements: inputs and outputs. Evaluating processes and their effectiveness in converting inputs into outputs provides an in-depth analysis of production at a micro level, where existing methods for evaluating production sustainability, particularly across the whole production chain, often fall short, as emphasized in the literature review (section 2.3.3 and 2.4.2). Therefore, an Input-Output Production Analysis Methodology (IOPAM), has been devised and will be detailed in the subsequent section, with further elaboration in Chapter 4.

Up to this point, the aspects of motivation, research problem, question, methodology, aim, goals, solution to research problem, and anticipated outcomes have been defined, shaping the research framework illustrated in Figure 3.12.

Figure 3.12: Comprehensive Research Framework



Source: The Author, Thesis Chapter 3, Section 3.9, p.56

1.4 An Input-Output Production Analysis Methodology

As elaborated in section 1.2, the components of production include inputs, outputs, and processes. Inputs refer to the tangible resources connected to land, labour, and capital, which can be quantified, along with entrepreneurship that, while intangible, can be evaluated qualitatively. Outputs comprise economic products and environmental emissions that are measurable, in addition to social factors that can be articulated qualitatively. Processes function to connect these inputs to the resultant outputs; however, they can also be reviewed as intangible inputs associated with entrepreneurship that help to demonstrate the direct relationship between inputs and outputs. This research explores these production components and seamlessly corresponds with an input-output analysis (IOA). However, the existing IOA related to production is limited and lacks a robust theoretical foundation. Moreover, this IOA examines production at a micro level, thereby rendering the validity of current methods irrelevant for this research. Consequently, this study introduces the IOPAM and its advancements to tackle the research question and fulfill its objectives, with a comprehensive development process detailed in Chapter 4. IOPAM seeks to promote better practices and support industry decision-making in the adoption of advanced methods that ultimately improve production sustainability.

IOPAM firstly integrates considerations for industry decision-making, applies the 5M/7M decision-making framework (what, where, who, why, when, which, where) (Čančer and Mulej 2013) efficacy corresponds with general empirical insights, and reframe the research question to the following dimensions:

What exactly is the problem?
- what currently is happening and at where?
- which are the alternatives?

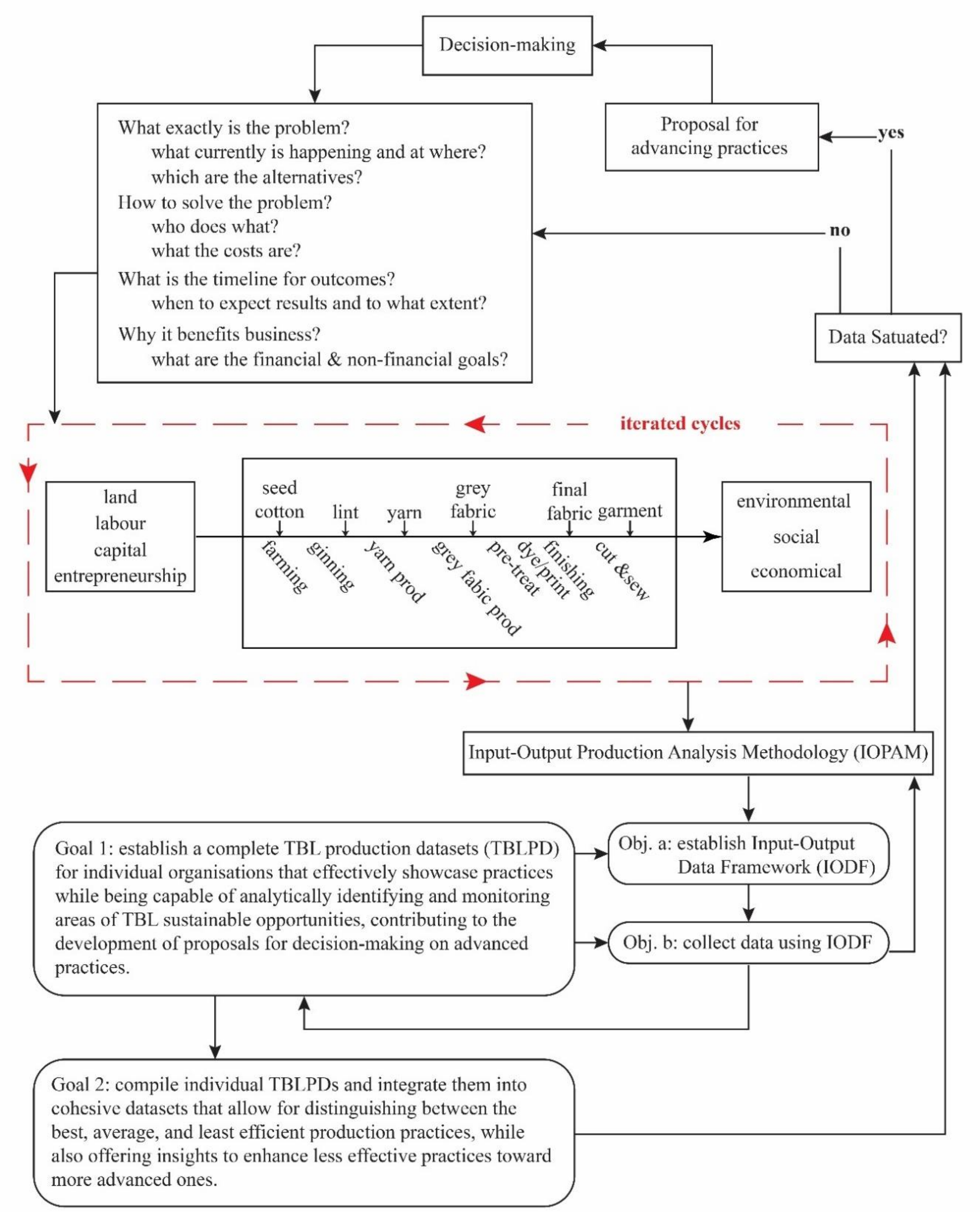
How to solve the problem?
- who does what?
- what the costs are?

Why it benefits business?
- what are the financial & non-financial goals?

What is the timeline for outcomes?
- when to expect results and to what extent?

The approach that directs these inquiries towards achieving the research objectives is an empirical, results-driven problem-solving method that manifests in iterative cycles, starting with a conceptual notion concerning production components and subsequently incorporating a thorough analysis of the cotton garment manufacturing process, which ranges from seeds to the finished product (elaborated in Chapter 5). Following this, a theoretical evaluation of cotton shirt production is conducted, aimed at assessing the global production impact of Australian cotton (explored in Chapter 6). This approach of developing IOPAM is illustrated in Figure 4.8.

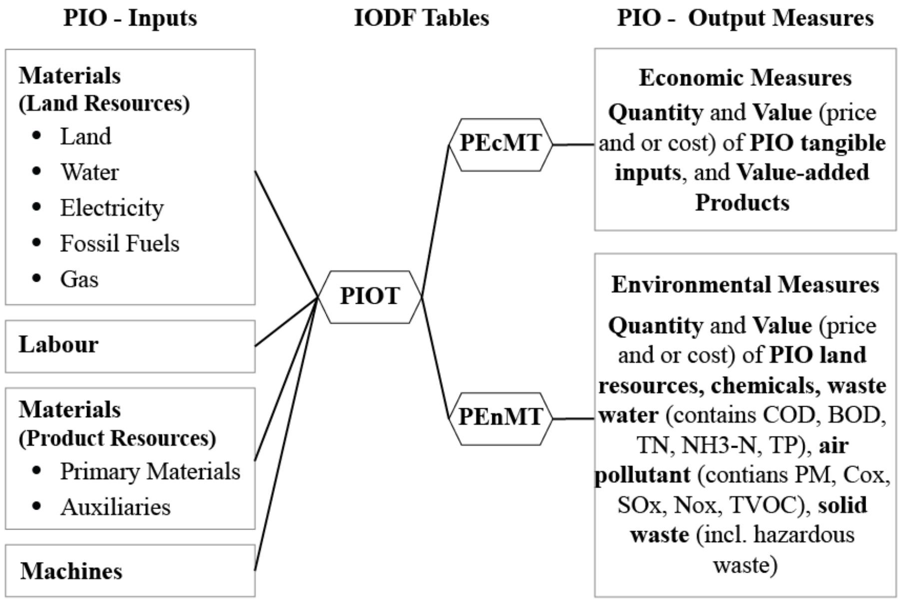
Figure 4.8 Result-driving Problem-solving for Development of IOPAM



Source: The Author, Thesis Chapter 4, Section 4.2.4, p.66

Through the iterative process, the components of production inputs and outputs are refined, and processes are integrated into four developed tools and two additional perspective tools, which collectively form the components of IOPAM, as illustrated in Figure 4.12. The four established tools comprise the Production Input-Output Flowcharts (PIOFs), the Production Input-Output Tables (PIOTs), the Production Economic Measures Table (PEcMT), and the Production Environmental Measures Table (PEnMT). PIOFs illustrates production practices concerning materials, machinery, and labour, ranging from cotton seeds to finished garments, employing flowcharts to promote a mutual understanding among both industry professionals and academics. PIOTs records production data related to PIOFs and provides information to PEcMT and PEnMT, thereby effectively connecting practices with TBL sustainability indicators. These tools together assemble quantitative production data directly aligned with research goals.

Figure 4.12: IOPAM Quantitative Components

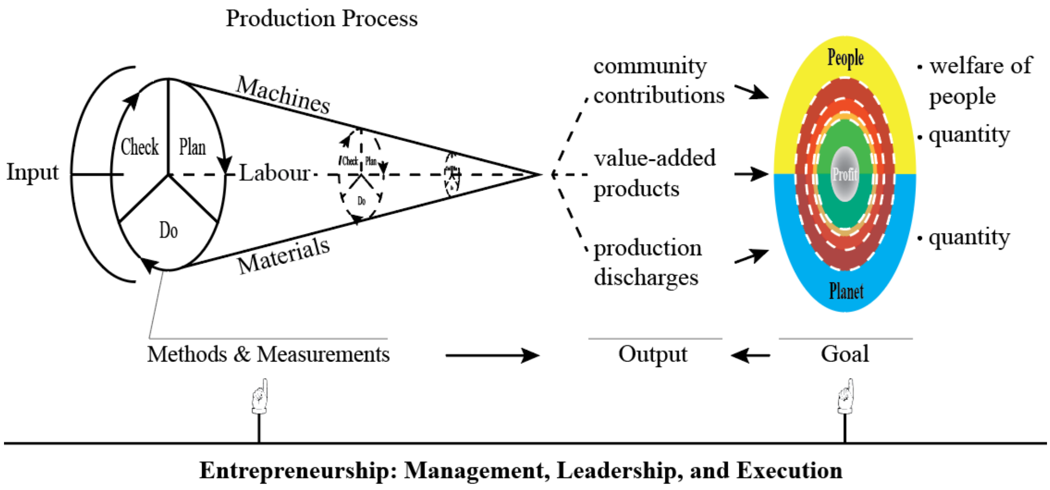


Source: The Author. Thesis Chapter 4, Section 4.3, p.70

Furthermore, the two perspective tools, Production Social Measures (PSM) and Production Entrepreneurship Measures (PEM), are tailored for doctoral-level research aiming for promoting qualitative dialogues concerning social challenges in the clothing sector, along with examining the effect of entrepreneurship on production outputs.

Developing IOPAM involves deep reflection on production management, leading to the emergence of a conceptual Input-Output Production Model (IOPMd) that captures the empirical insights into factors influencing production management effectiveness, as shown in Figure 4.14. This model, in turn, guides a management strategy cantered on data-driven innovation to foster sustainable practices in the clothing industry.

Figure 4.14: Input-output Production Model



Source: The Author. Thesis Chapter 4, Section 4.6.1, p.77

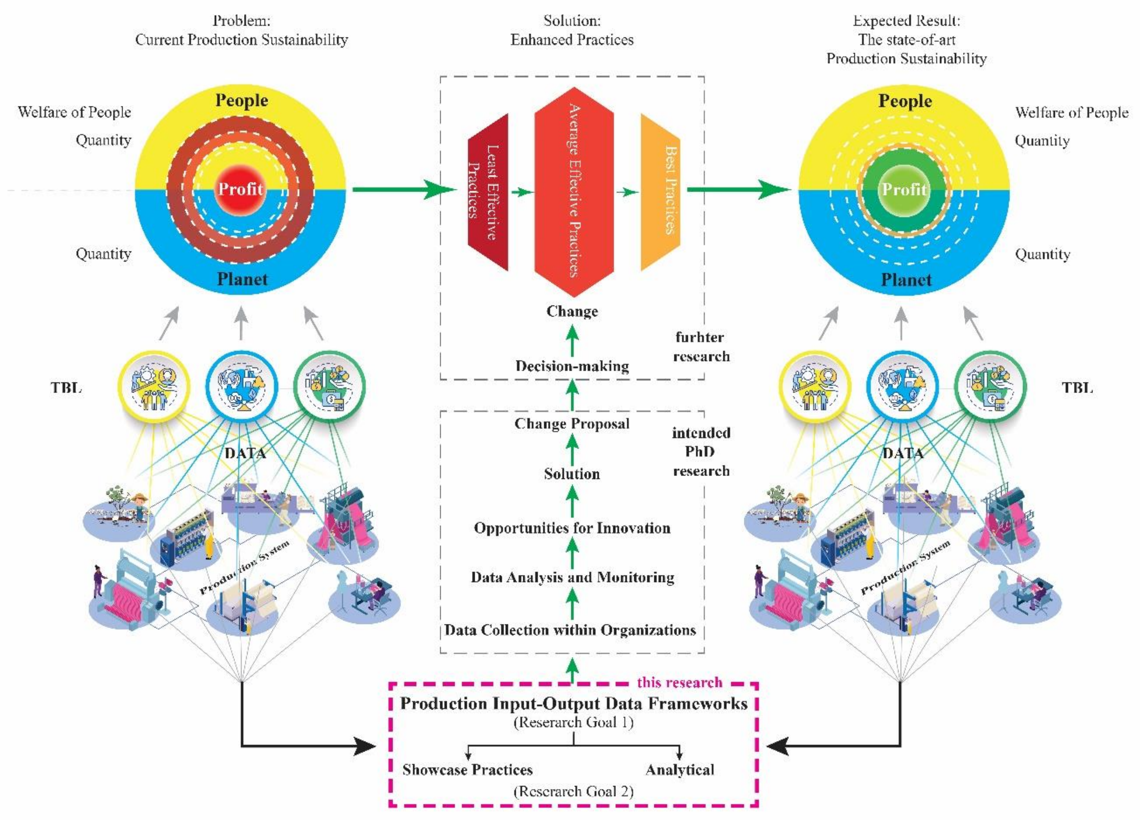
1.5 Outcomes and Contributions

Time constraints have prevented the research from fully achieving its goals, although one of the objectives has been met so far. The efforts have been focused on developing the IOPAM, which was designed to steer the inquiry toward the ultimate research aim. The ongoing advancement of the IOPAM currently leads to three key outcomes that can benefit both industry practice and academia.

The first outcome lies in the enrichment of a Production Input-Output Data Framework (PIODF), which supports data collection at the organizational level and ensures the research goals are met once data gathering and saturation are complete. The PIODF integrates the IOPMd (Figure 1.1) and the IOPAM Components (Figure 5.2). The IOPMd serves as a detailed framework that guarantees the integrity of the data collected and the analyses conducted within this structure, while the IOPAM Components, presently tailored for the cotton clothing production sector, are adequate for data collection in this field. As a result, the PIODF establishes a solid foundation for the proposed PhD research and propels initiatives aimed at evolving production sustainability into a cutting-edge standard, as depicted in Figure

4.15. This evolution is anticipated to commence at the organizational level, progressing to the sectoral level, and finally reaching the industrial level.

Figure 4.15: The Role of PIODF



Source: The Author. Thesis Chapter 4, Section 4.6.2, p.78

The PIODF may function as a self-assessment instrument and be employed by organizations to chronicle their production data, thereby enabling production analysis that could identify TBL opportunities such as augmenting product value, optimizing resource utilization, diminishing production effluents, and enhancing worker conditions. Additionally, it has the potential to be utilized throughout the wider fashion industry and could even catalyse sustainability improvements in other sectors, as the fundamental principles of production remain constant across industries, irrespective of the presence of physical outputs. Researchers have the option to adapt or employ the PIODF for gathering data that aligns with their unique field of study. Additionally, along with PIODF, a meticulously organized research design (Figure 1.2) that offers a definitive framework for promoting production sustainability in the fashion industry, inviting focused research to aid in achieving cutting-edge production sustainability.

The second outcome is that a comprehensive foundation of practical knowledge regarding the cotton clothing production within the industry context is established. This information encompasses 28 PIOFs that demonstrate as many as 100 processes, showcasing the transformation of materials, machinery, and labour into products, along with the associated discharges, although all of which require further refinement. Spanning from cotton seeds to completed garments, these processes are clearly presented, making them easily understandable to both industry professionals and academics, thereby fostering shared understanding. This knowledge also addresses a gap in the literature, as Sandin et al. (2019, page 109) acknowledged: "Knowledge of textile production processes is sparse and there is even less known about the environmental benefits and downsides of different techniques from a life cycle perspective." Hence, this knowledge is essential for research grounded in industry insights, as well as for the education about the clothing production.

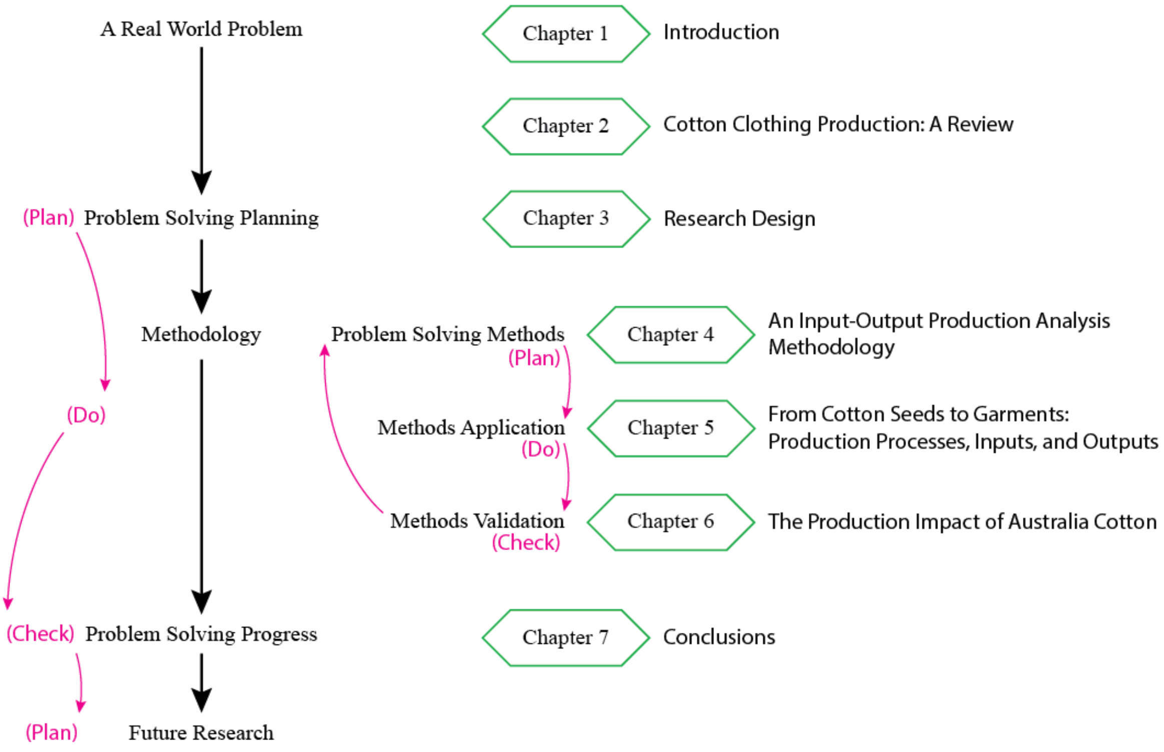
The third outcome arises from a hypothetical case study assessing the global production impacts of Australian cotton. This case study not only demonstrates the effectiveness of the IOPAM and the related expertise, but it also uncovers a considerable economic opportunity for the Australian cotton industry to expand, especially by establishing yarn production facilities in Australia to complete the production chain from seeds to garment manufacturing. This finding aligns with industry demands on the same issue as noted by the Australia Fashion Council. This case study also serves as a model for industry organizations to assess their production data, while also promoting more thorough research into the viability of achieving a complete cotton production chain in Australia.

All these outcomes and their contributions serve as key milestones of the research, reflecting its commitment to creating practical impacts, as it is motivated by the overarching aim of tackling a pressing global sustainability challenge within the fashion sector.

1.6 Thesis Outline

The IOPAM is built on a pragmatic epistemological foundation, emphasizing results-driven problem-solving and the plan-do-check (PDC) approach, which is relevant to the thesis organization. As depicted in Figure 1.1, the core of the research begins with a real-world issue that is elaborated upon and validated in chapters 1 and 2, followed by problem-solving planning detailed in chapter 3, then moving on to explore or establish a valid methodology for addressing the problem, which is accomplished in chapters 4, 5, and 6; ultimately, the progress of problem-solving is assessed at specific intervals to ensure the validity of the established methodology, with chapter 7 presenting the results.

Figure 1.1: Research Approach



Source: The Author

A more detailed outline of the thesis is provided below:

Chapter 1 Introduction

This chapter elaborates on the background that inspired this study, providing an overview of the entire thesis. It summarizes the research question, aim, goals, scope, boundaries, methodology, contributions, and structure.

Chapter 2 Cotton Clothing Production: A Review

This chapter explores the literature on cotton clothing production, emphasizing the limited knowledge of production and the absence of effective methods to improve production sustainability, underscoring the real-world challenge.

Chapter 3 Research Design

This chapter outlines the research trajectory, tracing the journey from the initial motivation of the study to its intended outcomes. It covers the refinement of the research question and objectives, defines the scope and boundaries of the research, discusses the need for developing an Input-Output Production Analysis Methodology, and addresses ethical considerations and data storage.

Chapter 4 An Input-Output Production Analysis Methodology

This chapter outlines the pragmatic epistemology that underpins and the IOPAM and its development framework, specifying the methodological components, including input and output indicators, methodological tools, data collection methods, production analysis techniques, along with its anticipated advancements.

Chapter 5 From Cotton Seeds to Garments: Production Processes, Inputs, and Outputs

This chapter presents a detailed Input-Output Production Flowcharts for cotton clothing, which visualizes the industry's production context. This is crucial for ensuring that the methodology accurately reflects industry practices. The flowcharts illustrate the operations within the production chain and shows how key inputs and outputs interact across different stages.

Chapter 6 The Production Impact of Australian Cotton

This chapter features a hypothetical case study crucial for developing Input-Output Production Tables, Production Economic Measures, and Production Environmental Measures, demonstrating their real-world relevance through practical application. This case study involves an input-output production analysis of Australian cotton, evaluating its triple bottom line impact on a global scale.

Chapter 7 Conclusion

This chapter outlines the recommended applications of the Input-Output Production Methodology and its contributions to date, as well as discussing the limitations of the research and directions for future study.

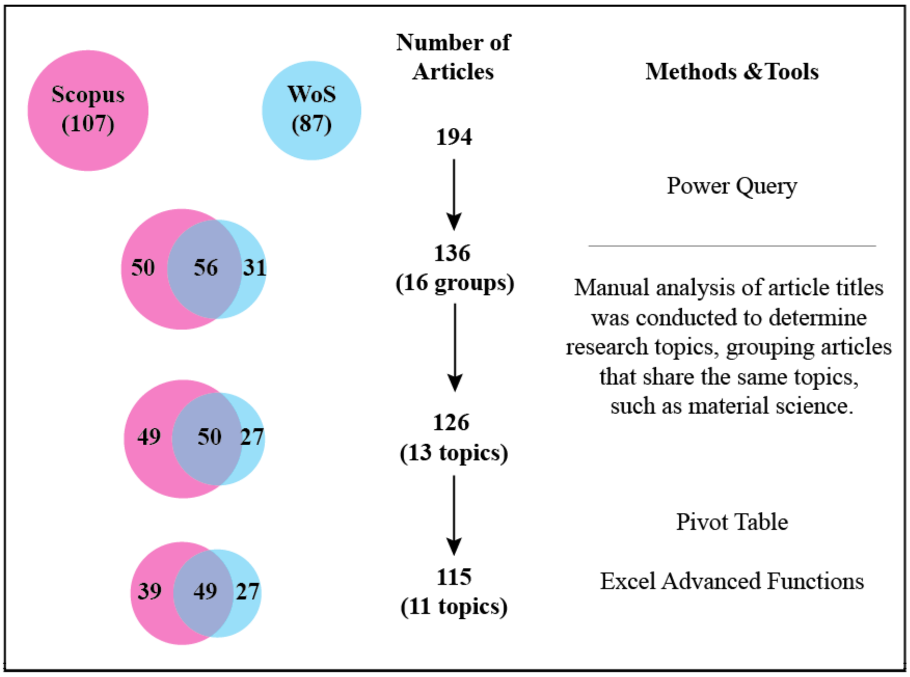
Chapter 2 Cotton Clothing Production: A Review

This chapter presents a literature review on cotton clothing production, revealing that while the impact of cotton production offers significant opportunities for enhancing sustainability, current research efforts practically supporting the industry's sustainable transformation are scarce. This gap is not merely academic; it has real-world implications for industry practices and sustainability efforts.

2.1 Methods

The literature for this review was gathered by searching selected keywords in article titles on the Web of Science (WoS) and Scopus platforms, which are renowned databases for sourcing high-quality research from peer-reviewed journals, books, and conference proceedings. Both platforms offer extensive data filtering options, such as WoS Categories and Scopus Subject Areas, and feature advanced data analysis functions with unparalleled data structures developed over decades (50 years for WoS and 20 years for Scopus). Initially, 87 articles from WoS and 107 articles from Scopus that are published since 2014 were collected for further filtering. The articles were then combined using Power Query and advanced Excel skills, resulting in a total of 194 articles. Those articles were carefully analysed based on their titles and abstracts and grouped into 13 research topics with a total of 31 sub-topics, plus 2 groups. Of these, 11 articles were excluded due to missing abstracts, missing authors (except for a report published in 2015, and from 2019 to 2022), or irrelevance to the research, resulting in 126 articles remaining. After careful consideration, the report (accounted for 5 counts) and an additional 6 articles (1 from Consumer Research and 5 from Cotton Historical Research) were excluded due to their limited relevance to the intended production investigation. Figure 2.1 presents a visualization of the source and filter process of the articles.

Figure 2.1: Source of Literature Review Articles



Source: The Author

It is important to acknowledge that subjectivity is inevitable throughout this chapter. The collection, interpretation and analysis of the literature are all influenced by the author's background, experiences, and viewpoints. While this subjectivity does not undermine the value of the review, it is essential to be aware of it and to consider it when evaluating the messages conveyed.

2.1.1 Search Keywords

The search keywords are designed to ensure that any articles with titles containing any of the following terms: textile, apparel, fashion, cloth, clothes, clothing, garment, garments, fiber, fibre, yarn, fabric, as well as any of the terms: product, manufacture, manufacturing, manufacturer, in conjunction with the term cotton, are gathered.

The WoS search query, which includes the aforementioned keywords, was refined using internal filters such as language, limiting results to English and Chinese. WoS categories unrelated to clothing production, such as medical science and mathematics, were excluded. This refined search returned 87 articles.

WoS Search Query:

((((TI=(textile OR apparel OR fashion OR cloth OR garment* OR fiber OR fibre OR yarn OR fabric)) AND TI=(product* OR manufact*)) AND TI=(cotton)) AND LA=(English OR Chinese)) AND WC=(Asian Studies OR Agriculture OR Anthropology OR Biodiversity & Conservation OR Public, Environmental & Occupational Health OR Chemistry OR Physics, Applied OR Thermodynamics OR Water Resources OR Area Studies OR Business & Economics OR Communication OR Development Studies OR Education & Educational Research OR International Relations OR GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY OR Government & Law OR Public Administration OR Social Issues OR Social Sciences - Other Topics OR Social Work OR Sociology OR Women's Studies OR Automation & Control Systems OR Computer Science OR Energy & Fuels OR Engineering, Multidisciplinary OR Engineering, Manufacturing OR Engineering, Industrial OR Engineering, Mechanical OR Engineering, Environmental OR Engineering, Electrical & Electronic OR Engineering OR Computer Science, Information Systems OR Materials Science, Textiles OR Operations Research & Management Science OR Robotics OR Science & Technology - Other Topics OR Transportation)*

Applying the same principle to the Scopus search query, as detailed below, returned 107 articles.

Scopus Search Query:

(TITLE (textile OR apparel OR fashion OR cloth* OR garment* OR fibre OR fiber OR YARN OR FABRIC) AND TITLE (product* OR manufact*) AND TITLE (cotton) AND LANGUAGE (english OR chinese)) AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (EXCLUDE (SUBJAREA,"CHEM") OR EXCLUDE (SUBJAREA,"PHYS") OR EXCLUDE (SUBJAREA,"BIOC") OR EXCLUDE (SUBJAREA,"MATH") OR EXCLUDE (SUBJAREA,"AGRI") OR EXCLUDE (SUBJAREA,"MEDI") OR EXCLUDE (SUBJAREA,"IMMU") OR EXCLUDE (SUBJAREA,"PHAR") OR EXCLUDE (SUBJAREA,"VETE") OR EXCLUDE (SUBJAREA,"NURS") OR EXCLUDE (SUBJAREA,"NEUR") OR EXCLUDE (SUBJAREA,"HEAL") OR EXCLUDE (SUBJAREA,"PSYC")) AND (EXCLUDE (DOCTYPE,"cr") OR EXCLUDE (DOCTYPE,"ed") OR EXCLUDE (DOCTYPE,"er") OR EXCLUDE (DOCTYPE,"no") OR EXCLUDE (DOCTYPE,"tb"))

2.1.2 Research Topics

Article titles “plays an important role as the first point of contact between writer and potential reader and may decide whether or not the paper is read (Haggan 2004, page 1 in Abstract)” and “need to be informative (Frisch 1964)”. It is observed that good research papers have informative titles that unambiguously identify the research topic and focus. After carefully examining gathered article titles and their abstracts, 13 research topics with 27 sub-topics are established and presented in Table 2.1.

Table 2.1: Research Topics

Research Topics		Sub-topics	
List	Description	List	Description
1	Circular Economy Research	(a)	Cotton Material Waste Use in other Industries
		(b)	Cotton Material Waste Use within Textile Industry
		(c)	Chemical/Water from Dyeing, Printing, and Finishing Reuse
		(d)	Review
2	Cotton Material Application in other Industries		
3	Innovations within Production from Cotton Seeds to Products	(a)	Cotton Farming
		(b)	Cotton Ginning
		(c)	Dyeing, Printing, and Finishing Process
4	Material Science	(c)	Cotton/Cotton Blended Fiber
		(d)	Cotton/Cotton Blended Yarn
		(e)	Cotton/Cotton Blended Fabric
5	Energy Consumption	(a)	Electricity Usage
		(b)	Fuel & Gas
		(c)	Process & Machinery
6	LCA/Carbon Footprint/Waste Water Footprint/Chemical	(a)	LCA
		(b)	Carbon Footprint
		(c)	Waste Water Footprint
		(d)	Chemical
		(e)	LCA Review
7	Products and Production Process	(a)	Completed Process from Seeds to Garments
		(b)	Specific Process
		(c)	Product Development
		(d)	Cost Control
		(e)	The Relation between Process and Semi/Final Product
8	Industrial Cluster/Localization of Cotton Supply Chain		
9	Cotton Material Quality, Properties, Price, and Trading Related Research	(a)	Material Performace and Production
		(b)	Price and Trading
10	Transportation		
11	Industrial Case of Sustainability Transition		
12	Consumer Research		
13	Cotton Historical Research	(a)	Production
		(b)	Trading

Source: The Author

2.2 Data Statistics

In this section, a statistical examination of the 115 articles across 11 research topics is performed to unveil emerging themes in the literature. Consequently, comprehensive statistics illustrate different aspects pertaining to these articles, such as the distribution of research topics, the count of articles featuring author keywords, the years of publication for the articles, and a word cloud of article keywords.

Table 2.2 showcases the distribution of 115 articles across various research topics, indicating that the research predominantly concentrates on three areas: innovations, circular economy, and material science, which account for 63%.

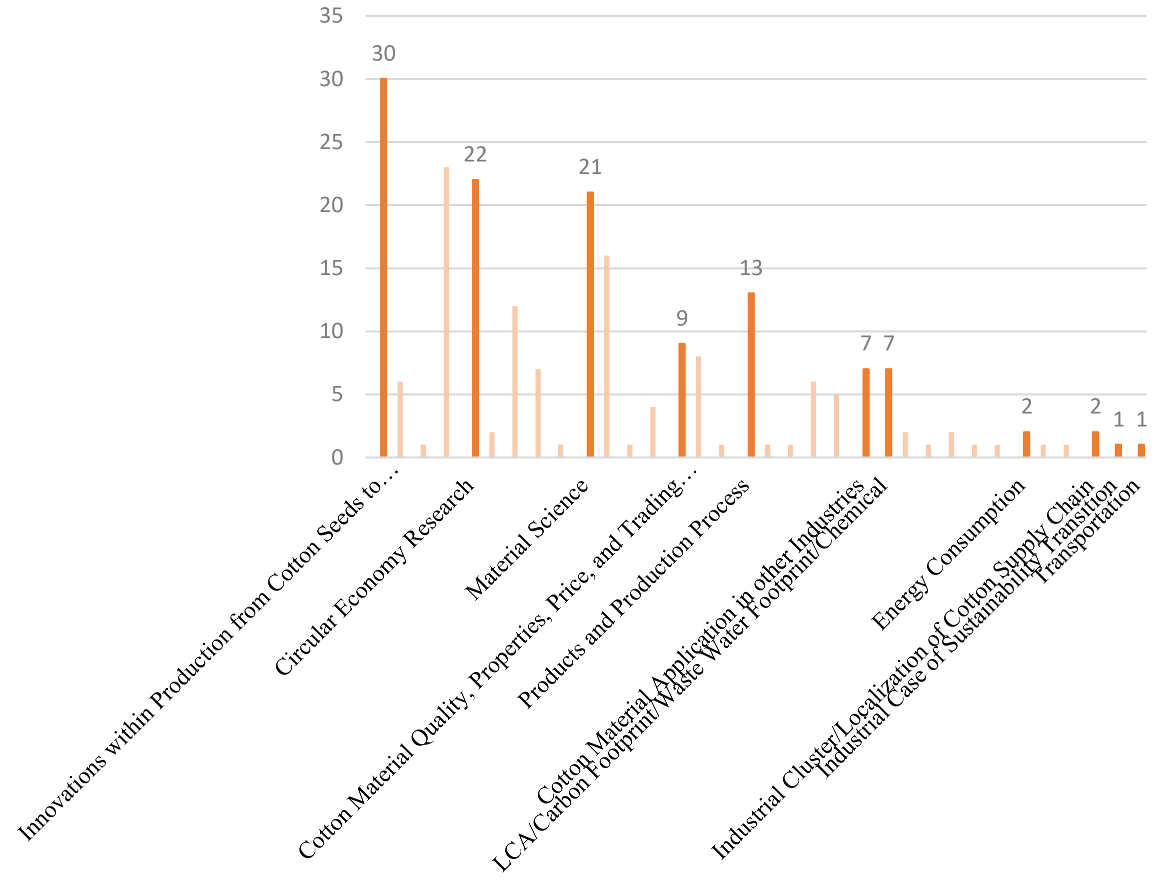
Table 2.2: Number of Articles in Each Research Topics

Innovations within Production from Cotton Seeds to Products		30
Cotton Farming	6	
Cotton Ginning	1	
Dyeing, Printing, and Finishing Process	23	
Circular Economy Research		22
Chemical/Water from Dyeing, Printing, and Finishing Reuse	2	
Cotton Material Waste Use in other Industries	12	
Cotton Material Waste Use within Textile Industry	7	
Review	1	
Material Science		21
Cotton/Cotton Blended Fabric	16	
Cotton/Cotton Blended Fiber	1	
Cotton/Cotton Blended Yarn	4	
Cotton Material Quality, Properties, Price, and Trading Related Research		9
Material Performace and Production	8	
Price and Trading	1	
Products and Production Process		13
Completed Process from Seeds to Denim, Encyclopedic Informa	1	
Cost Control	1	
Product Development	6	
The Relation between Process and Semi/Final Product	5	
Cotton Material Application in other Industries		7
LCA/Carbon Footprint/Waste Water Footprint/Chemical		7
Carbon Footprint	2	
Chemical	1	
LCA	2	
LCA Review	1	
Waste Water Footprint	1	
Energy Consumption		2
Electricity Usage	1	
Process & Machinery	1	
Industrial Cluster/Localization of Cotton Supply Chain		2
Industrial Case of Sustainability Transition		1
Transportation		1
Total		115

Source: The Author

Figure 2.2 offer a visualization of the article distribution.

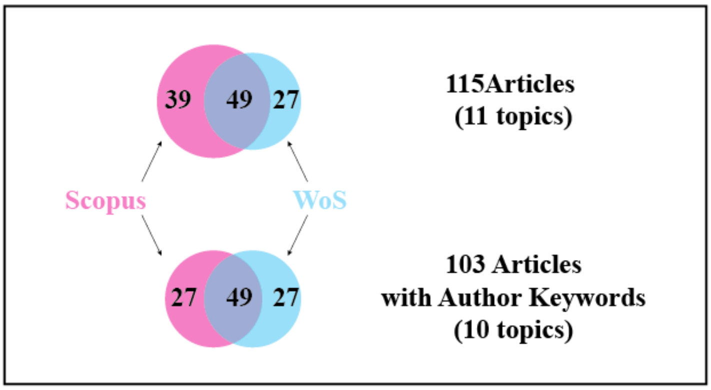
Figure 2.2 Number of Articles of Research Topics



Source: The Author

Among the 115 articles, 11 are missing Author Keywords in the Scopus database. Majority of them are conference papers. These articles lose visibility during the review stage.

Figure 2.3 No. of Articles & Articles with Author Keywords



Source: The Author

The absence of author keywords across various research topics is illustrated in Table 2.3.

Table 2.3: No. of Articles with Author Keywords

Research Topics/Sub-Topics	No. of Articles with Author Keywords	No. of Articles
Circular Economy Research	21	22
Cotton Material Waste Use in other Industries	11	12
Cotton Material Application in other Industries	6	7
Cotton Material Quality, Properties, Price, and Trading Related Research	8	9
Material Performace and Production	7	8
Price and Trading	1	1
Energy Consumption	1	2
Electricity Usage		1
Process & Machinery	1	1
Industrial Case of Sustainability Transition		1
Industrial Cluster/Localization of Cotton Supply Chain	1	2
Innovations within Production from Cotton Seeds to Products	27	30
Cotton Farming	5	6
Cotton Ginning		1
Dyeing, Printing, and Finishing Process	22	23
LCA/Carbon Footprint/Waste Water Footprint/Chemical	7	7
Material Science	20	21
Cotton/Cotton Blended Fabric	15	16
Products and Production Process	12	13
The Relation between Process and Semi/Final Product	4	5
Transportation	1	1
Grand Total	103	115

Source: The Author

Out of the 115 articles, 45 were published from 2014 to 2019, with the remaining 70 being published post-2020. Table 2.4 displays the number of articles published within each research topic across different time periods, while Figure 2.4 offers a visual representation of this data.

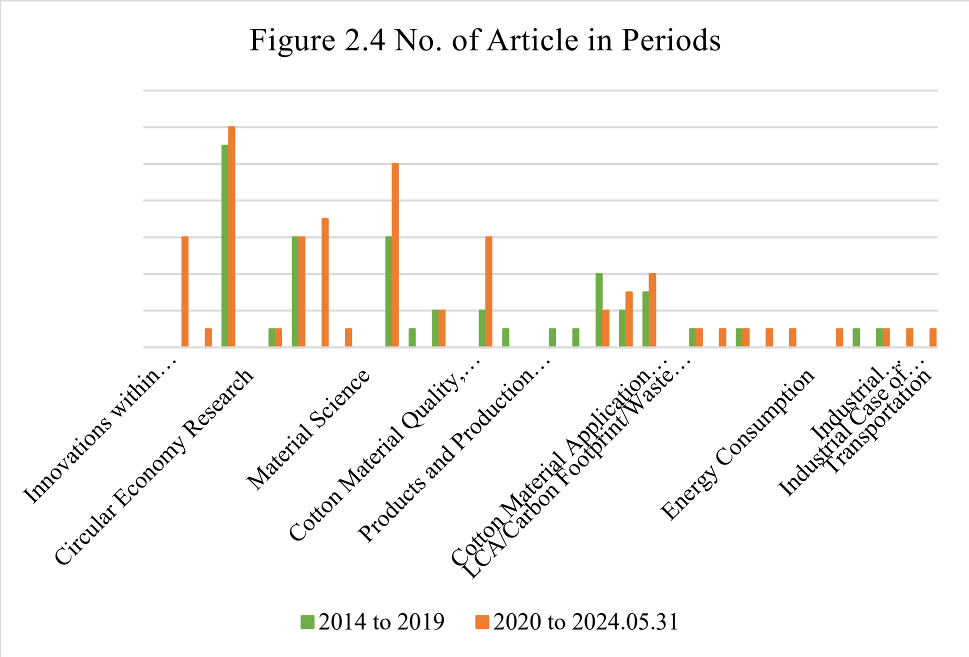
Table 2.4: No. of Articles in Each Research Topics by Year Range

Research Topics		2014 to 2019	2020 to 2024.05.31
Innovations within Production from Cotton Seeds to Products			
	Cotton Farming		6
	Cotton Ginning		1
	Dyeing, Printing, and Finishing Process	11	12
Circular Economy Research			
	Chemical/Water from Dyeing, Printing, and Finishing Reuse	1	1
	Cotton Material Waste Use in other Industries	6	6
	Cotton Material Waste Use within Textile Industry		7
	Review		1
Material Science			
	Cotton/Cotton Blended Fabric	6	10
	Cotton/Cotton Blended Fiber	1	
	Cotton/Cotton Blended Yarn	2	2
Cotton Material Quality, Properties, Price, and Trading Related Research			
	Material Performace and Production	2	6
	Price and Trading	1	
Products and Production Process			
	Completed Process from Seeds to Denim, Encyclopedic Information	1	
	Cost Control	1	
	Product Development	4	2
	The Relation between Process and Semi/Final Product	2	3
Cotton Material Application in other Industries		3	4
LCA/Carbon Footprint/Waste Water Footprint/Chemical			
	Carbon Footprint	1	1
	Chemical		1
	LCA	1	1
	LCA Review		1
	Waste Water Footprint		1
Energy Consumption			
	Electricity Usage		1
	Process & Machinery	1	
Industrial Cluster/Localization of Cotton Supply		1	1
Industrial Case of Sustainability Transition			1
Transportation			1
	Total	45	70

Source: The Author

A visual presentation of articles in periods is presented in Figure 2.4.

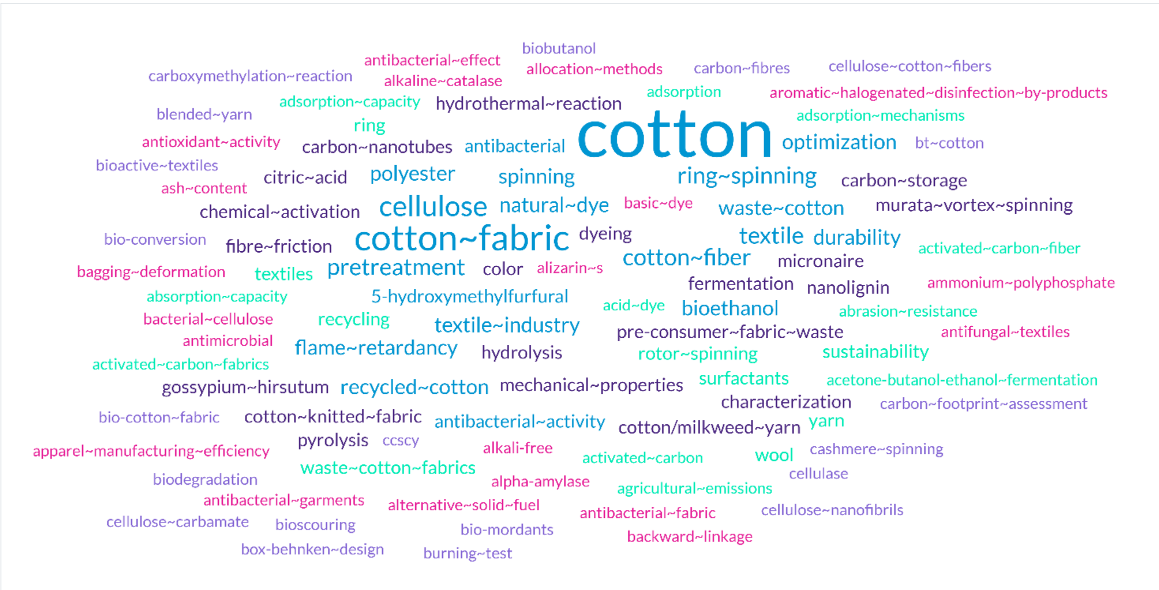
Figure 2.4: No. of Articles in Periods



Source: The Author

The 103 articles with Author Keywords provided 547 keywords, of which 454 are unique. The top 100 original keywords are displayed in a word cloud in Figure 2.5, generated through a free online word cloud generator.

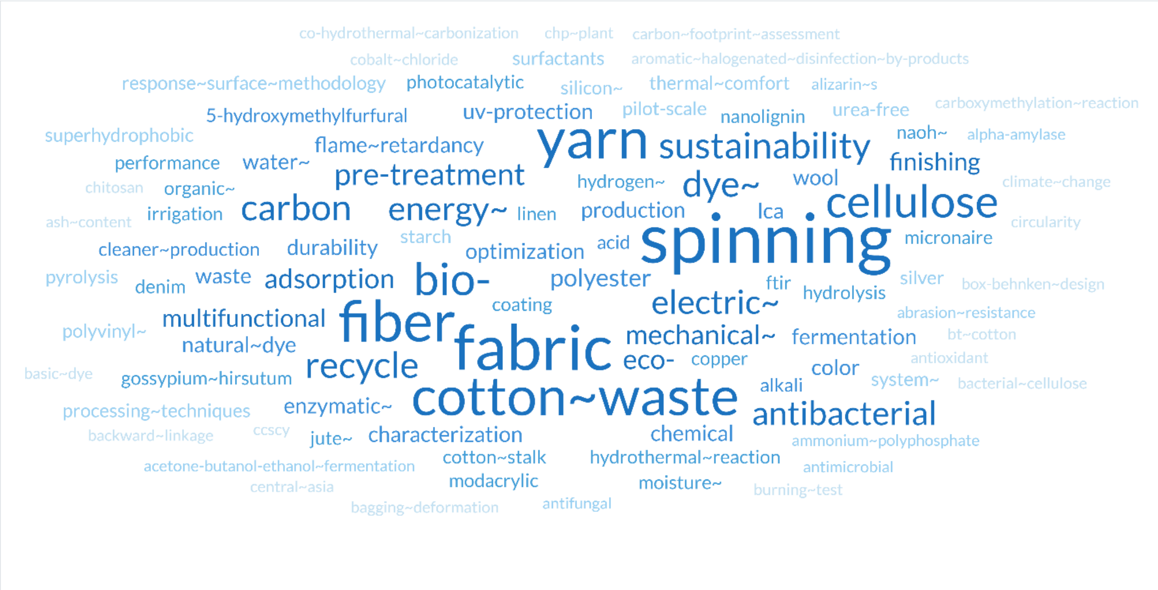
Figure 2.5: Author Keywords Presentation through Word Cloud



Source: Created by the Author through Generate Word Cloud (freewordcloudgenerator.com)

To better highlight the key points discussed by the authors, the original Author Keywords were refined to cluster those with similar phrases, such as 'spinning.' All keywords containing or having a similar meaning to 'spinning' were consolidated into the refined keyword 'spinning.' This refinement resulted in 276 unique keywords, providing a more focused representation of the discussion on cotton clothing production, as shown in Figure 2.6.

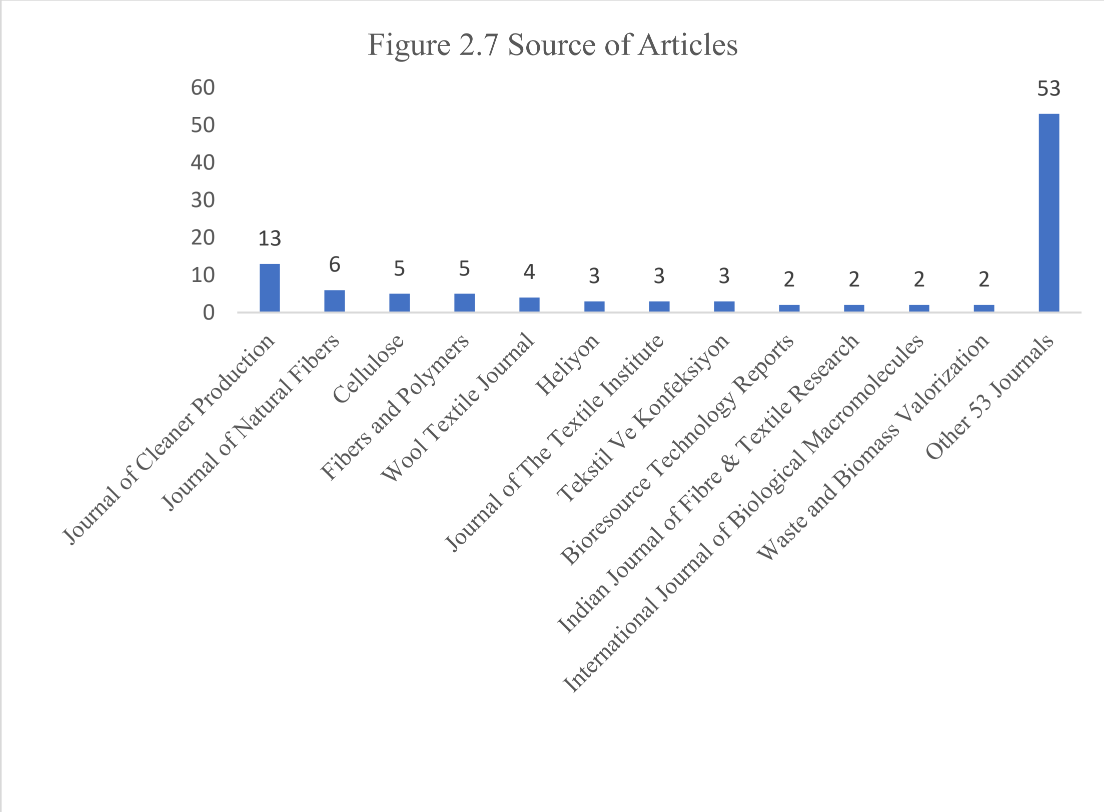
Figure 2.6: Cotton Clothing Production Keywords Presentation through Word Cloud



Source: Created by the Author through [Generate Word Cloud (freewordcloudgenerator.com)]

These Word Cloud presentations indicate that the research is spread across various facets related to the product, highlighting a shortfall in its association with production. Additionally, these articles originate from 65 different sources, with 50 articles coming from 12 journals and one article each from the other 53 journals, further illustrating the fragmented nature of the research. Notably, the journal that published the highest number of those 103 articles is the Journal of Cleaner Production (13 articles), signifying that production sustainability research is a focal point. Collectively, these presentations underscore the significance of production sustainability research; however, the actual production research remains limited.

Figure 2.7 presents the illustration of source contributions.



Source: The Author

2.3 Literature Presentation

The purpose of this literature review is to highlight the current understanding related to cotton industry and subsequently compile data to enhance clothing production database that aids industry decision making in making choice to enhance practices. Therefore, the literature presentation reflects this purpose and is strategically organized as follows:

First, section 2.3.1, "The Cotton Industry's Versatile Potential: From Raw Material to End Products" highlights insights from articles on research topics such as Circular Economy Research, Cotton Material Application in Other Industries, Cotton Material Quality, Properties, Price, Trading-Related Research, Industrial Cluster/Localization of Cotton Supply Chain, Innovations within Production from Cotton Seeds to Products, Material Science, Industrial Cases of Sustainability Transition, and Transportation. This segment is concisely introduced to highlight their pertinent capabilities, with no additional elaboration required since they lack the ability to enhance the clothing production database.

Second, section 2.3.2, "Insufficient Knowledge Exists Regarding Cotton Clothing Production" highlights a significant research gap that arises from a focused review on cotton

clothing production processes, summarizing insights from articles on Products and Production Process, and Energy Consumption, as well as relevant subjects discussed in the previous sections. No further elaboration can be provided.
Lastly, section 2.3.3, "Sustainability Assessments and Methods," provides a comprehensive overview of the articles related to the research topics of 'LCA/Carbon Footprint/Wastewater Footprint/Chemicals' and 'Energy Consumption,' detailing their significant findings and the methodologies employed.

2.3.1 The Cotton Industry's Versatile Potential: From Raw Material to End Products

Though cotton is chiefly employed in the textile sector, it is noteworthy that the cotton waste produced within this industry is either being utilized or is under scrutiny for potential use across other industries. Cotton, along with its waste, holds the potential to be converted into an array of products including carbon materials (Jagdale et al. 2017; Matveev et al. 2022; Zhu et al. 2021), bacterial nanocellulose and enzymes (Guo et al. 2016), bioethanol (Nikolić, Pejin, and Mojović 2016), microcrystalline cellulose (MCC) (Yulina et al. 2020), 5′ hydroxymethylfurfural (HMF) ((Kawamura, Sako, Ogata, and Tanabe 2020; Kawamura, Sako, Ogata, Mine, et al. 2020), solid fuel (Xu et al. 2021), gas diffusion layers for fuel cells (Navarro et al. 2021), and wearable smart products (Cai et al. 2018; Zeng et al. 2021), among others.

Moreover, cotton is not only versatile in its application across various industries but also possesses specialized applications intrinsic to the textile industry itself. It provides an array of functional attributes such as in UV protection, antibacterial properties, antioxidant benefits, hydrophobicity, flame retardancy, and ease of care, to name a few. Emerging trends illustrate the inventiveness and advancements in material techniques concerning these areas (Barani and Mahltig 2020; Juikar and Vigneshwaran 2017; Mostafa et al. 2018; Nosheen et al. 2023; Ranjbar-Mohammadi 2018). alongside the investigation of specialised materials, such as low-bagging stretch denim yarn (Rahim, Rahman, and Uddin 2023), but predominantly fabrics (Chen and Lin 2018; Kakonke et al. 2020; Pisitsak, Tungsombatvisit, and Singhanu 2018; Xiao et al. 2020). Those functions of material can also achieved through finishing process at industry Dyeing, Printing and Finishing sector and investigated by various researchers ((Baseri 2020; Demirbağ Genç and Alay-Aksoy 2022; Ibrahim et al. 2019; Kertmen et al. 2020).

There is a consensus among industry and academia that Dyeing, Printing and Finishing sector is one of the most environmentally damaging phases within clothing production. Efforts, including those endeavoured to the material functional attributes mentioned above, count for around 22% of 115 articles. Other efforts contributed to circular economy, natural dye, or processes. In contribution to circular economy, Wang, Yu, and Dong investigation in reuse of waste alkali from rayon manufacturing process for cotton fabric pretreatment (Wang, Yu, and Dong 2019) and (Cifci et al. 2022) investigate in reuse cellulosic wastes to synthesis of Zncl2 activated raising powder for acid and basic dye adsorption. Echinacea and Patience Seed (Yilmaz, Gültepe, and Uygur 2023), Euclea Divinorum (Welsh, Taschetto, and Quinn 2022), and Weld (Karadag 2022) are all investigated in as natural dye material. Majeed, Iftikhar, and Mukhtar targeted water-efficient in textile printing (Majeed, Iftikhar, and Mukhtar 2024).

Furthermore, innovations in both farming (Hussain, Ali, and Gardezi 2021; Koudahe et al. 2024; Velmourougane et al. 2022; Zang et al. 2021) and ginning processes (Azizov et al. 2021) have further augmented the quality and adaptability of cotton. Cumulatively, these developments are paving the way for extensive opportunities in sustainable growth.

2.3.2 Insufficient Knowledge Exists Regarding Cotton Clothing Production

Out of the 115 articles examined, fewer than 10% (13 articles) specifically focus on the processes that convert raw cotton into finished products (such as yarn or fabric), and none of them explore the entire production chain from raw cotton to clothing. Of these 13 articles, 12 focus on specific products or techniques in production practices (Xinghua et al. 2021; 王前文 et al. 2016), relationship between techniques (Anam et al. 2019), spinning parameters (Akankwasa, Wang, and Zhang 2016), and strain characteristics (Baymuratov et al. 2021). These studies aim to enhance the understanding of how different blending and spinning methods affect the final product's quality and performance.

In addition to the limited research on yarn production, previously discussed technologies and innovations in materials, dyeing, printing, and finishing also highlight the need for deeper understanding. These areas are crucial for the overall environmental impact of cotton clothing production, yet they remain underexplored in practical settings. Advanced techniques in dyeing and finishing processes can significantly reduce water and chemical use, which are major environmental concerns in the textile industry. However, the sparse knowledge base hampers the industry's ability to adopt these innovations effectively.

This lack of comprehensive and applicable knowledge regarding production leads to many previously mentioned (section 2.3.1) innovations and theoretical advancements failing to translate into widespread improvements in the industry, thus leaving them as untapped potential and ongoing research topics. Furthermore, this knowledge gap is evident in the evaluation and analysis of sustainability within the clothing sector, highlighting a disparity between theoretical concepts and practical application, as noted by Sandin et al. (2019, page 109), "Knowledge of textile production processes is sparse, and even less is known about the environmental benefits and downsides of different techniques from a life cycle perspective." This rift lessens the influence of academia in guiding industry decisions, particularly in relation to adopting more sustainable practices.

2.3.3 Sustainability Assessments and Methods

The fashion industry is estimated to be responsible for 8% (4-5 billion tonnes) of the global GHGs (Quantis 2018), 20% of global wastewater (United Nations Climate Change 2018), and 35% of oceanic primary microplastic pollution (190,000 tonnes). It consumes 79 trillion litres of water and produces 92 million tons of waste annually (Global Fashion Agenda and The Boston Consulting Group 2017). Cotton clothing production is a significant contributor to these impacts, considering that cotton accounts for approximately 25% of all materials used in the industry.

There are efforts focused on assessing the sustainability of the fashion industry regarding its environmental and social impacts; however, there is a noticeable neglect of the cotton clothing sector, especially with regard to the entire production chain. Out of the 115 articles examined, 6 articles focused on sustainability assessment, while 2 articles addressed energy consumption, as detailed in Table 2.5.

Chen et al. (2024) conducted a full life cycle carbon footprint (CF) analysis compared cotton/kapok blended T-shirts to pure cotton T-shirts using a carbon storage accounting method. They concluded that 1 kg of pure cotton T-shirts produces 9.469 kg of CO2 equivalents (CO2eq), while 1 kg of cotton/kapok blended T-shirts results in -24.249 kg CO2eq. In terms of carbon storage, pure cotton T-shirts store -15.653 kg CO2eq, whereas cotton/kapok blended T-shirts store -43.442 kg CO2eq. Study of Günther et al. (2017) however, include both carbon (CO2) and phosphorus (P) footprint analysis of cotton and apocynum (a type of bast fibre crops) farming process in Xinjiang and concluded that cotton fibres have a climate footprint of 4.43 kg CO2e per kg, an energy footprint of 30.90 MJ per kg, and a phosphorus footprint of 101 g P per kg. In comparison, apocynum fibres have much lower impacts, with a climate footprint of 1.93 kg CO2e per kg, an energy footprint of 21.85 MJ per kg, and a phosphorus footprint of 1.6 g P per kg.

Table 2.5: List of Articles relation to Sustainability Assessment

<table>
<tr><th>Article Title</th><th>Authors</th><th>Research Topics</th><th>Sub-topics</th></tr>
<tr><td>Impact of Additional Carbon Storage of Natural Plant Fiber on Product Carbon Footprint: A Case Study of Cotton/Kapok Blended T-Shirt Vs Pure Cotton T-Shirt</td><td>Chen et al. (2024)</td><td rowspan="7">LCA/ Carbon Footprint/ Waste Water Footprint/ Chemical</td><td rowspan="2">Carbon Footprint</td></tr>
<tr><td>Carbon and Phosphorus Footprint of the Cotton Production in Xinjiang, China, in Comparison to An Alternative Fibre (Apocynum) from Central Asia</td><td>Günther et al. (2017)</td></tr>
<tr><td>Environmental Impact Assessment of Multi-Pollutant Emission in Cotton Fabric Production</td><td>Wang et al. (2021)</td><td>Waste Water Footprint</td></tr>
<tr><td>Ecotoxicological Impact Assessment of the Production of Cotton Fabric</td><td>Qian et al. (2020)</td><td>Chemical</td></tr>
<tr><td>A Systematic Review of the Life Cycle Environmental Performance of Cotton Textile Products</td><td>Chen et al. (2023)</td><td>LCA Review</td></tr>
<tr><td>An Integrated Life Cycle Assessment Approach for Denim Fabric Production Using Recycled Cotton Fibers and Combined Heat and Power Plant</td><td>Fidan, Aydoğan, and Uzal (2021)</td><td rowspan="2">LCA</td></tr>
<tr><td>Life Cycle Assessment of Cotton Textile Products in Turkey</td><td>Baydar, Ciliz, and Mammadov (2015)</td></tr>
<tr><td>Consumption of Electric Energy in the Production of Cotton Textiles and Garments</td><td>Angelova et al. (2021)</td><td rowspan="2">Energy Consumpt ion</td><td>Electricity Usage</td></tr>
<tr><td>Energy and Exergy Analyses of Finishing Process in Cotton Textile Production</td><td>Yin and Guo (2015)</td><td>Process& Machinery</td></tr>
</table>

Wang et al. (2021) employed the total environmental impact score (TEIS) methodology to assess the wastewater generated from the fabric dyeing, printing, and finishing processes, finding that the environmental damage caused by wastewater released during batch dyeing was the most significant, followed by pretreatment and after-finishing processes. The authors determined that phosphorus had the most significant influence, accounting for 41.5% of the total environmental impact, stemming from the chemical inputs. However, Qian et al. (2020) assert that alcohol ethoxylate and sodium hydroxide are the primary chemical pollutants when examining toxicity during the dyeing, printing, and finishing stages. The researchers utilized a quantitative structure-activity relationship (QSAR) model to evaluate the ecotoxicological effects of cotton woven fabric during the weaving and wet treatment processes.

Last but certainly not least, Life Cycle Assessment (LCA) is recognized as a key instrument for assessing the sustainability of the textile and apparel sector. (Fadara, Wong, and Maulana 2023). This is further supported by the fact that out of six articles cantered on sustainability evaluation, three of them employed LCA methodologies, including the study by Chen et al. (2023), which utilized LCA for analysing carbon footprints, along with a review of LCA concerning cotton products.

Fidan, Aydoğan, and Uzal (2021) analysed the environmental impacts of eight varieties of cotton denim, tracing the journey from cotton seeds to the final denim fabric, while also incorporating assessments of product quality and cost efficiency. The authors utilized a range of data sources, including a denim fabric manufacturer from Turkey. Their study concluded that 100% recycled cotton, when utilizing combined heat and power (CHP), demonstrates the best performance in terms of environmental benefits, product quality, and cost savings. Baydar, Ciliz, and Mammadov (2015) conducted a study comparing the environmental effects of Eco T-shirts made from organically cultivated cotton and dyed with eco-friendly recipes against those of conventional T-shirts. They found that Eco T-shirts have a lower potential for environmental impact; however, the global warming potential remains the most significant environmental concern for both conventional and Eco T-shirts, primarily arising from the usage phase, followed by cultivation, harvesting, and fabric processing stages.

The challenge with the LCA lies in the varying outcomes from diverse studies, as supported by the review performed by Yin and Guo (2015), which compiles published findings regarding the environmental performance of cotton apparel using various environmental impact assessment techniques, such as life cycle assessment, carbon footprint, and water footprint. The authors emphasize that substantial efforts are necessary to develop the accounting modules, which should consist of multiple components, each depicting a production stage of cotton apparel and incorporating an inventory of inputs relevant to that stage, including cotton cultivation (water, fertilizer, pesticides) and spinning (electricity), among others.

While many LCAs consider the sustainability effects of energy use, it is crucial to emphasize that efficient energy consumption plays a vital role in improving both environmental and economic sustainability; therefore, considerable resources are focused on energy consumption. Angelova et al. (2021) succinctly outlined the energy profile of the manufacturing processes from fibres to finished garments during the IOP conference, covering spinning, weaving, finishing, and garment production. The authors determined that the electric energy consumption during the garment manufacturing phase ranges from 0.065 to 0.195 kWh/kg, whereas the electric energy use during the spinning phase falls between 3.24 and 3.47 kWh/kg. Yin and Guo (2015) perform energetic and exergetic evaluations on the finishing stage of cotton textile manufacturing, utilizing real operational data. The authors determine that the lowest levels of energy and exergy efficiencies occur during the singeing process. The highest degree of irreversibility is related to the hot oil boiler, succeeded by the washing stages in mercerising and washing II in desizing. The most significant energy losses are associated with the washing process in mercerizing and the stenter.

These investigations yielded quantitative data that could act as a reference point for related studies; nevertheless, they provided scant insight into industry practices. Furthermore, the methodologies employed concentrated either on a singular aspect of sustainability (such as wastewater, carbon, chemicals, or energy) or on comparative analyses aimed at pinpointing a better alternative among others (like LCA). (Giacomin and Pacca 2024) As a result, those methods are inadequate for research aimed at pinpointing opportunities to improve practices that support the essential industry transformations necessary for advancing sustainability.

For instance, a significant LCA investigation on 6 types of garment led by Mistra Future Fashion (Fletcher and Tham 2019a) suggests that the production stage of a cloth's life cycle accounts for 79.9% of its total environmental impact, while the remaining 20.1% is linked to other stages, including transportation, distribution & retail, usage, and disposal. (Sandin et al. 2019) However, the study faces challenges in production analysis and provides only a cursory overview that falls short from an industry standpoint. The researchers acknowledge this constraint and remark that "*Knowledge of textile production processes is sparse and there is even less known about the environmental benefits and downsides of different techniques from a life cycle perspective.*" (p. 109). Consequently, while they advocate for a transition to renewable energy to alleviate the environmental burden of production, the economic feasibility of such a shift remains uncertain, and no practical solutions can be devised, making it improbable for industry decision-making to act on such suggestions.

2.4 Bridging the Gaps: Advancing Production Expertise and Sustainability Assessment Methods

The literature reveals two major gaps in research on cotton clothing production: first, there is a lack of adequate knowledge concerning the production of cotton clothing, and secondly, the existing methods for evaluating the sustainability of the cotton clothing sector do not effectively support research intended to guide industry choices toward adopting more sustainable practices. Collectively, the current research has had a minimal effect on the industry for improvement on sustainability.

Bridging these gaps is crucial for improving the sustainability of the clothing industry, which has faced significant hurdles for numerous initiatives over the last 30 years as global warming increasingly threatens humanity. Only through collaborative efforts and effective strategies that engage academia, industry, and all relevant stakeholders can we make meaningful progress toward sustainability, ensuring that technological advancements and innovations produce tangible environmental, economic, and social benefits. In the quest for sustainable production within the cotton clothing sector, a thorough understanding of the actual production factors and outcomes could guide the development of impactful methods that foster sustainable production.

2.4.1 Understand Production: Input, Output, and Processes

Production refers to a series of processes for the creation and allocation of value. (Frisch 1964; Kurz, and Salvadori 1995) Witt clearly articulates it as "*the process of generating a specified outcome, i.e., a state or process with certain properties or, in economic terms, a certain 'output' by means of some 'inputs'*". (Witt 2003, p.2) This definition highlights the elements of production, including input, output, and the processes involved, while also indicating their economic context. Classic economics initially identifies the factors of production, which encompass tangible inputs such as land, labour, and capital, and later included entrepreneurship that can manifest in various forms, including processes, methods, practices, intangible inputs, and so forth, ultimately adapting to the ongoing evolution of production phenomena. Although precisely defining these factors may be challenging, an overview of each, compiled from diverse collective resources (Frisch 1964; Kurz, and Salvadori 1995; Witt 2003; Velu and D 2015; Open AI 2024), is provided below:

> Land: refers to all natural resources available for production. It includes not only the physical land itself but also everything that is derived from it, such as minerals, water, forests, and energy sources. Land is a fixed factor of production, and its availability is limited.
>
> Labour: represents the human effort, both mental and physical, that is exerted in the production process. It includes the skills, knowledge, and expertise of workers. Labour is a variable factor of production as its quantity and quality can be adjusted according to the needs of production.
>
> Capital: refers to the man-made goods that are used in the production process to create other goods and services. It includes machinery, equipment, tools, buildings, and infrastructure. Capital can be divided into two categories: physical capital (such as machinery) and financial capital (such as funds for investment).
>
> Entrepreneurship: involves the ability to combine the other factors of production (land, labour, and capital) in innovative and productive ways. Entrepreneurs take risks and make decisions to organize and manage the production process. They identify opportunities, allocate resources, and innovate to create new products, services, or processes.

Production outputs, on the other hand, are regarded as value-added products or services by "for-profit" businesses that engage production mainly to achieve economic gain. (Hinton 2020). The fashion industry predominantly consists of for-profit organisations, and the undeniable reality is that their profit from production hinges on the allocation of resources and labour, which regrettably but inevitably leads to discharge. (Muthu 2020) However, the overall effect is deemed detrimental, thereby escalating the demand for the industry to incorporate environmental and social considerations in the pursuit of economic results, indicating the necessity of the TBL framework for the outputs. The Triple Bottom Line (TBL) has been widely recognised as "a sustainability framework that examines a company's social, environment, and economic impact". It was initially created to "encouraging businesses to track and manage economic (not just financial), social, and environmental value added - or destroyed." (Elkington 2018; 25 Years Ago I Coined the Phrase "Triple Bottom Line." Here's Why It's Time to Rethink It; Harvard Business Review)".

Consequently, inquiries into production must concentrate on assessing both tangible and intangible inputs and outputs that illustrate the TBL framework, which includes land, labour, capital, entrepreneurship, value-added products, environmental emissions, and social consequences. In addition, analysing the sustainability of production should incorporate these elements, enhancing the current IO methods, as detailed in the subsequent section.

2.4.2 Assess Production Sustainability through Input-Output Methods

The study of production through an input-output method has been evidenced since the 17th century by Mercantilists and Physiocrats (Mattila, 2013). Quesnay's Tableau Economique stands as the prototype of an input-output matrix, demonstrating the flow of goods as early as 1758. A hundred years later, Bogdanov (1873–1928) gained recognition for formally establishing the input-output (IO) concept during his presentation at the All-Russia Conference on the Scientific Organization of Labour and Production Processes (1921) (Belykh 1989). Subsequently, study employing the input-output method transitioned from a focus on production to a concentration on economics. Leontief (1906-1999) refined the IO concept into a robust analytical framework, allowing it to evolve and gain empirical validation, ultimately leading to the creation of general equilibrium theory and input-output analysis (IOA) for examining economic phenomena (Belykh 1989; Miller and Blair 2009).

Building on Leontief's contributions, Input-Output Analysis (IOA) has become a vital component of modern global economics, with most countries now incorporating input-output tables into their national accounting systems (Hauschild, Rosenbaum, and Olsen 2018). Life Cycle Assessment (LCA) integrates IOA through Life Cycle Inventory Assessment (LCIA), establishing it as a key element of LCA. Since the late 1990s, IO models have been increasingly applied at industrial and corporate levels, particularly in management domains such as business management (Lin and Polenske 1998) and supply chain management (Albino, Izzo, and Kühtz 2001).

The application of IO methods in the fashion industry is limited and mostly from the last 10 years. A literature search on WoS and Scopus databases through article titles that contain both keywords 'input*' and 'output*', along with either 'textile*', 'apparel*', 'fashion', 'cloth*', or 'garment*', yielded 15 articles result relevant to the industry, as listed in Table 2.6.

Table 2.6: List of Articles relation to Input-Output Methods

Article Title	**Authors**	**Document Type**	**Pub. Year**
Industrial Correlation Evolution of Textile Industry in Sichuan Province Based on an Input-output Model	Shao G.-Y.; Fang G.; Xiang X.; Wang T.	Conference Paper	2024
The role evolution of textile industry in China's economy during 2002-2020: an input-output analysis	Zhang, Jianlei; Weng, Shengbin; He, Lin	Research Article	2024
Input–output analysis as guidance for the Brazilian textile supply chain	Giacomin A.M.; Pacca S.A.	Research Article	2024
Developing a Framework on Designing a Sustainable Supply Chain by Integrating Input-Output Analysis and DEMATEL Method: A Case Study on Textile Industry in Indonesia	Trihastuti D.; Dewi D.R.S.; Santosa H.; Yuliawati E.	Research Article	2024
Analysis of Industrial Correlation Evolution of Beijing Textile and Garment Industry based on an Input-output Model	Deng J.; Zheng Y.	Conference Paper	2023
Research on the correlation relationship of guangdong province textile manufacturing industry based on input-output	Li T.-Y.; Fang G.	Conference Paper	2019
Research on the ripple effect of China textile industry based on input-output method	Wu J.; Liu L.; Lu A.	Conference Paper	2019
Hotspot identification in the clothing industry using social life cycle assessment—opportunities and challenges of input-output modelling	Zamani B.; Sandin G.; Svanström M.; Peters G.M.	Research Article	2018
Multiplier Decomposition in the Textile Industry among Korea, China and Japan : Focused on the World Input-Output Table	Lee, Choon-Keun; Sohn, Soo-Seok	Research Article	2016
Inter-industrial Analysis in Textile Industries among Korea, China and Japan on International Input-output Table	Lee, Choon-Keun	Research Article	2015
The input-output's control strategy of the fashion company	Jiang L.; Hu S.; Tian B.	Research Article	2015
Evaluation of environmentally benign production program in the textile-dyeing industry (I): An input-output analysis	Wu C.-C.; Chang N.-B.	Research Article	2007
A Study on Korea's Textile Industry and the Milan Project: Using the Daegu Region's Input-Output Model	Young-Jae, Kim，; Lee, Choon-Keun; Yeo, Taek-Dong	Research Article	2004
Suitable combination of inputs for improving outputs in DEA with determining input congestion: Considering textile industry of China	Jahanshahloo G.R.; Khodabakhshi M.	Research Article	2004
An Input-Output Analysis of The American Textile Industry: A Synthesis of Several Techniques Applied to A Revision of The United States Department of Commerce 1958 Input-Output Study	RICE, PHILIPFOY	Dissertation /Thesis	1968

A review of these articles through screening indicates that, similar to LCA, their explicit connection to industry practices seems to be rather minimal, especially as none of the IOM in application relevant to production elements pertinent to land, labour, capital, entrepreneurship, value-added products, environmental emissions, and social impacts simultaneously. Consequently, these IOMs fall short for research focused on identifying opportunities to enhance practices that foster the vital industry transformations needed to promote sustainability. Achieving this necessitates a grassroots-level input-output production analysis, which refers to a bottom-up IO approach.

2.4.3 Learn from Effective Initiatives Tackling Sustainability

In response to the worldwide demand for sustainability, nations are launching various initiatives. Notably, two initiatives that actively involve the fashion sector have proven to be particularly advantageous and enlightening for studies aimed at enhancing sustainability or assessing environmental impacts. The first is the integration of national best practices within the Australian cotton industry, which aims for economic viability while simultaneously enhancing environmental and social performance. The most valuable lesson from the Australian cotton industry's sustainability efforts is that strong leadership plays a crucial role in steering the industry towards its sustainability goals. The second is the concerted efforts of the Ministry of Ecology and Environment of the People's Republic of China (MEEPRC) to address environmental challenges across various industries, including fashion. The key takeaway from this initiative is the quantification of environmental impacts, which facilitates manageable control and governance.

<u>The Australian Cotton Industry</u>

The Australian cotton industry stands out for its economically successful strategies and progressive environmental and social performance. The industry's model aligns closely with the methodology's goal of leveraging the triple bottom line for sustainable production. This alignment suggests that the Australian cotton industry's operational model serves as a foundational exemplar, for how the methodology's objectives can be realized.

"Sustainability for the Australian cotton industry means running profitable and efficient businesses while creating environmental, economic and social value. It also means being

accountable to stakeholders for the industry's actions and impacts." (Australian Cotton Industry's Sustainability Working Group 2019, page 6)

The Australian cotton industry's precise sustainability definition sets goals that have directed the industry towards significant advancements, positioning it as a global paragon of sustainability today. This is acknowledged for its high yields and the exceptional quality of the cotton lint produced. Yield-wise, Australian irrigated cotton achieves the highest output per unit area among all leading cotton-producing nations, with figures approximately 2.5 times higher than the global average. The upward trend in yields is evident, having advanced from 5.3 bales per hectare in the 1970s to 6.2 bales in the 1980s, reaching 7 bales in the 1990s, and now consistently surpassing 10 bales per hectare. (Welsh et al. 2022). Regarding quality, Australia stands as the foremost provider of premium-grade and zero contaminated cotton fibre to the international market. The Australian cotton industry takes pride in its commitment to continual advancement and reliably supplies high-quality fibre that benefits spinners with fewer breakages and stoppages, enhanced throughput efficiency, and yarn uniformity (Australian Cotton Shippers Association 2022)

The environmental sustainability achievement is remarkable as well. Compared to 1992; Australian cotton growers are now use 97% less pesticides and 52% less water, while also utilizing 34% less land for each bale of cotton produced (Cotton Research Development Corporation). Compared to the global landscape, Australian cotton growers focus intensely on best practices, consistently achieving the highest yields per hectare (Zhao and Tisdell 2009) and delivering superior quality (Australian Cotton Shippers Association 2022).

The accomplishments of the Australian cotton industry can be credited to what the author contends is a PDC (Plan-Do-Check) operational model, which has been the cornerstone of the industry for over three decades. The PDC operational model is articulated as follows:

Plan: A unified leadership and collaborative effort, outlined in Table 2.7, envisions a sustainable future for the Australian cotton industry. This plan centres on the pivotal aspects of cotton cultivation and is buttressed by extensive research. These robust leadership and collaboration networks have developed an array of tools such as the Cotton Production Manual, the myBMP (Best Management Practices) Information Bank, and the Gross Margin Budget. All these resources are founded on meticulous research and profound industry insight, providing comprehensive and systematic guidance to aid cotton growers in their agricultural practices.

Do: With the direction and support from leadership, Australian farmers commit their efforts to managing the agricultural process, monitoring individual yields and expenditures, and ensuring profitability.

Check: The united leadership and collaborative bodies gather feedback either through direct participation in the farming process or by collecting insights from the farmers themselves. They then evaluate the impact of their endeavours and adjust their planning content and timelines to foster further improvement.

Table 2.7: Australian Cotton Industry Leadership and Collaboration

Leadships	Position Description	Year Established	Founders	Source
Commonwealth Scientific and Industrial Research Organisation (CSIRO)	to carry out scientific research to benefit Australian industry and the community, and to contribute to the achievement of national objectives.	1949	Australian Government	Commonwealth Scientific and Industrial Research Organisation | Directory
Cotton Research and Development Corporation (CRDC)	work with industry to invest in research, development and extension (RD&E) for a more profitable, sustainable and dynamic cotton industry. The purpose of the CRDC is to support the performance of the cotton industry: helping to increase both productivity and profitability of our growers.	1990	Australian Government	https://www.directory.gov.au/portfolios/agriculture-fisheries-and-forestry/cotton-research-and-development-corporation
Cotton Australia	support Australia's cotton growers and represent their interests It facilitated a link between growers, researchers, research funding bodies, government and industry groups.	2008	Australian Cotton Growers Research Association (ACGRA) Australian Cotton Foundation (ACF)	https://cottonaustralia.com.au/cas-history
MyBMP	myBMP sets the industry's best practice performance criteria and provides a framework by which growers can participate in, and be accredited in, best practice.	2010*	CRDC Cotton Australia	mybmp.com.au/cottoninfo.aspx
CottonInfo	CottonInfo is primarily a communications program, designed to deliver research and development outcomes and best practice information to growers and the wider industry.	2012	Cotton Australia CRDC CSD	mybmp.com.au/cottoninfo.aspx
Cotton Seed Distributors Ltd.	CSD is a sole supplier of Australian cotton seeds and a major investor in cotton breeding, research and development.	1967	Australian Cotton Growers	Company HisB3:F8tory - Cotton Seed Distributors (csd.net.au)

Source: The Author

Environmental Control Effort of MEEPRC

China is home to the world's largest textile industry, which consequently bears a significant environmental burden. However, due to a lack of quantifiable measures, the extent of the impact associated with exact sources within the industry remains unclear, leading to a scarcity of efforts aimed at mitigating these environmental effects. To address this issue, the Ministry of Ecology and Environment of the People's Republic of China (MEEPRC) undertook its first National Pollution Source Census, covering industrial, agricultural, and domestic pollution sources. This census began in 2007 and spanned over two years. A second census was conducted from 2017 to 2019. These censuses aim to thoroughly understand and grasp the number, distribution, and environmental impact of various pollution sources within China, enabling the government to better formulate and implement environmental protection policies.

The census utilized a range of methods, including on-site investigations, questionnaires, and remote sensing technology, to gather data. Through such efforts, the government can more accurately assess the environmental impacts, develop targeted pollution prevention and control measures, and enhance the level of environmental management. Comparing the data from the two censuses, significant environmental progress has been made over the past decade. In 2017, emissions of pollutants such as sulfur dioxide, chemical oxygen demand, and nitrogen oxides decreased by 72%, 46%, and 34% respectively compared to 2007. Moreover, the number of wastewater treatment, desulfurization, and dedusting facilities in industrial enterprises increased to 2.4 times, 3.3 times, and 5 times their 2007 levels, respectively (中国网 2020). While the specific enhancements in the fashion industry are not yet fully disclosed, the author's exchanges with a wide array of Chinese professionals at the 134th Canton Fair have affirmed these progresses. Nonetheless, a suite of tools encompassing environmental impact measures has been crafted to quantify production pollution specifically for sectors within the textile and fashion industry. Table 2.8 presents a list of sectors that now have various measures in place to estimate the pollution generated by an individual entity, a regional industry, or the entire industry based on the quantity of their production output. Among these indices, the Cotton Weaving and Processing Production Pollution Index (1712) and the Cotton Textile Dyeing, Printing, and Finishing Production Pollution Index (1713) include activities associated with cotton weaving, dyeing, printing, and finishing. Meanwhile, the Knitting or Crochet Fabric Dyeing, Printing, and Finishing Production Pollution Index (1762) encompasses the processes of knitting or crochet fabric dyeing, printing, and finishing.

Table 2.8: Textile Sectors Featuring the MEEPRC Pollution Index

Code	Production Pollution Indexes for the Textile and Fashion Sectors (Original Description in Chinese)	Production Pollution Indexes for the Textile and Fashion Sectors (The Author Translated)
1712	棉织造加工行业行业系数手册	Cotton Weaving and Processing
1713	棉纺织及印染精加工行业系数手册	Cotton Textile Dyeing, Printing, and Finishing
1721	毛条和毛纱线加工行业系数手册	Wool Top and Yarn Processing
1723	毛染整精加工行业系数手册	Wool Dyeing and Finishing
1731	麻纤维纺前加工与纺纱行业系数手册	Hemp Fiber Pre-Spinning and Spinning
1733	麻染整精加工行业系数手册	Hemp Dyeing and Finishing
1741	缫丝加工行业系数手册	Silk Reeling Processing
1743	丝印染精加工行业系数手册	Silk Dyeing and Finishing
1751	化纤织造加工行业系数手册	Polyester Weaving and Processing
1752	化纤织物染整精加工行业系数手册	Polyester Fabric Dyeing, Printing, and Finishing
1762	针织或钩针编织物印染精加工行业系数手册	Knitting or Crochet Fabric Dyeing, Printing, and Finishing
1781	非织造布制造行业系数手册	Nonwoven Fabric Manufacturing
1819	其他机织服装制造行业系数手册	Other Weaving Garment Manufacturing
191	皮革鞣制加工行业系数手册	Leather Tanning Processing
192	皮革制品制造行业系数手册	Leather Product Manufacturing
1921	皮革服装制造行业	Leather Apparel Manufacturing Industry
1922	皮箱包（袋）制造行业（行李箱）	Leather Luggage and Bags Manufacturing (Suitcases)
1923	皮手套及皮装饰制品制造行业（皮带）	Leather Gloves and Decorative Leather Goods Manufacturing (Belts)
1929	其他皮革制品制造行业（钱包）	Other Leather Product Manufacturing (Wallets)
193	毛皮鞣制及制品加工行业系数手册	Fur Tanning and Product Processing
1931	毛皮鞣制及制品加工行业产污系数表	Fur Tanning and Product Processing
194	羽毛（绒）加工及其制品制造行业系数手册	Feather (Down) Processing and Product Manufacturing
1941	羽毛（绒）加工产污系数表	Feather (Down) Processing
1942	羽绒制品制造行业产污系数表	Down Product Manufacturing
195	制鞋行业系数手册	Footwear Manufacturing
1951	纺织面料鞋制造行业	Textile Fabric Footwear Manufacturing
1952	皮鞋制造行业	Leather Footwear Manufacturing
1952	皮鞋制造行业	Leather Footwear Manufacturing
1954	橡胶鞋制造行业	Rubber Shoe Manufacturing
1959	其他制鞋业行业	Other Footwear Manufacturing

Chapter 3 Research Design

In response to the growing global demand for the fashion industry to address its environmental and social impacts, a significant real-world challenge, this research was initiated by the author's intent to validate her reflections on production management within the industry. Specifically, she aimed to demonstrate that production practices can be improved for both environmental benefits and economic gains. Upon reviewing existing literature, the author sought robust, industry-based evidence but instead discovered a gap between academic research and industry practices. This finding motivated her to undertake this research, with the goal of providing solid, industry-grounded evidence to support decision-making for more sustainable practices in the fashion industry.

Before embarking on this study, the author had a cause-and-effect mindset that underpinned result-driven problem-solving, the Plan-Do-Check approach, and an input-output perspective. This thinking logic likely stems from the author's extensive problem-solving experience in various production roles within the industry and forms the foundation for research design and methodology development. This chapter documents the design process that leverages this thinking logic to address the sustainability impact of the fashion industry. The subsequent chapter (Chapter 4: An Input-Output Production Analysis Methodology) theorizes this thinking logic, leading to the development of a methodology and its tools that hold promising potential for transitioning fashion production to a sustainable future.

The key stages of the research design include refining the research problem, formulating research questions and objectives, and exploring methods to address the research problem. This process follows an extensive literature review, discussed thoroughly in Chapter 2, which uncovers gaps in existing knowledge and methodologies that may lack the potential to effectively address the research problem or connect the research query with the desired outcomes.

3.1 A Real-world Problem

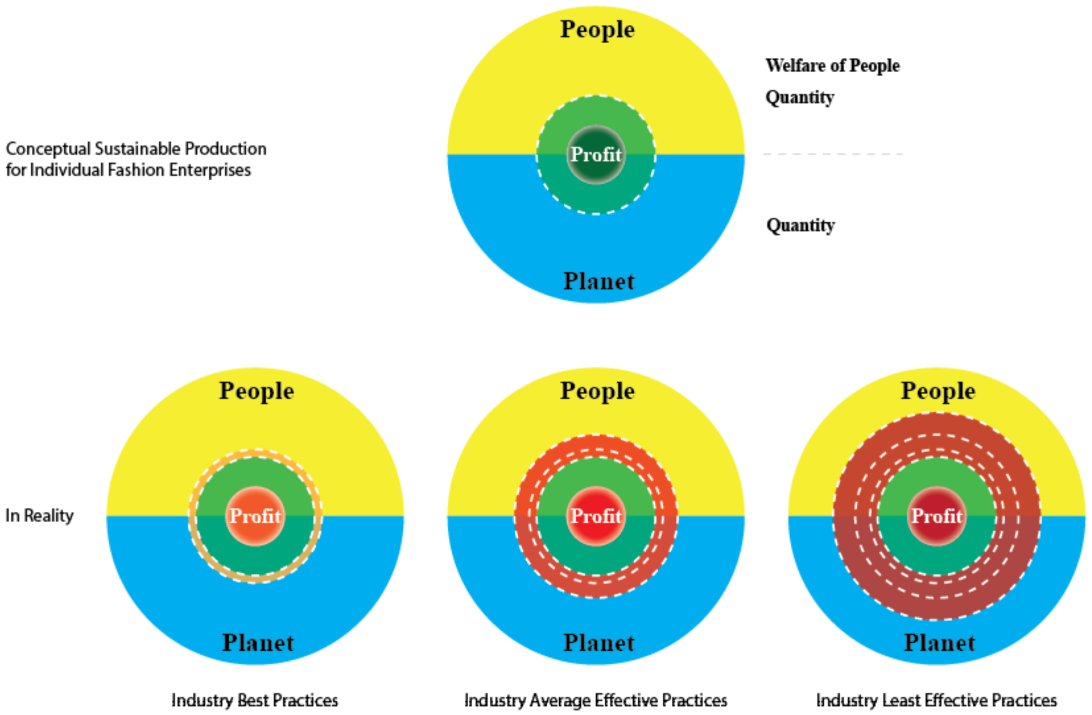
The sustainability issues of the fashion industry are the effects of the production practices. Hence the current practices can be improved to directly enhance economic and environmental benefits and may also improve social benefits, either directly or indirectly. An instance where fabric patterns fail to meet desired requirements is often caused by information distortion during oral communication. This issue can have detrimental effects, including the need to allocate time, resources, and costs to rectify the problem. For example, it can lead to a shortened production lead time in garment manufacturing, which in turn can introduce additional challenges and compromise the overall quality of the final product. Implementing standardized communication methods can effectively mitigate such issues and enhance the accuracy of information exchange.

Another noteworthy example is the frequent occurrence of half-empty containers during the transportation of bulk garments. This not only results in unnecessary carbon emissions but also represents an inefficient use of resources. Additionally, once the bulk garments arrive at the retailer's warehouse, they often remain unsold or unused for extended periods. This lack of inventory turnover can lead to financial losses and underutilization of the available stock.

In both cases, enhanced understanding and collaboration among key stakeholders across the production chain can significantly reduce these problems, as well as decrease duplicated work and faulty products, lower costs, increase productivity, and ultimately boost economic, environmental, and social sustainability. These cases also indicate that different practices are linked to varying levels of resource use efficiency, product output quality and quantity, discharge amounts, and sustainable labour engagement.

A product cannot be made without some form of social and environmental impact in this industrial era (Muthu 2020). It's an objective fact that production profit must come from the allocation of resources and labour that are quantifiable in terms of numbers, with the latter also measured by the degree of people's welfare. Theoretically, optimal practices lead to sustainable production by realizing profits with zero waste, balanced labour, and no excess emissions, without pressuring supply chains to adopt unsustainable methods (conceptual sustainable production). However, in reality, production profits are frequently attained by employing more resources than necessary (or the best the industry can offer), less responsible engagement with people, or both, with the extent varying based on different practices. The best industry practices currently minimize environmental and social disturbances, but there is potential for improvement to approach and push the theoretical limits of sustainable production. In contrast, the least effective practices lead to significant depletion of planetary systems, a disregard for people's welfare, or both. Average effective practices contribute to the current level of sustainability in the fashion industry, which is considered harmful to the environment and raises significant social concerns. Figure 3.1 illustrates the relationship between different production practices and the level of production sustainability.

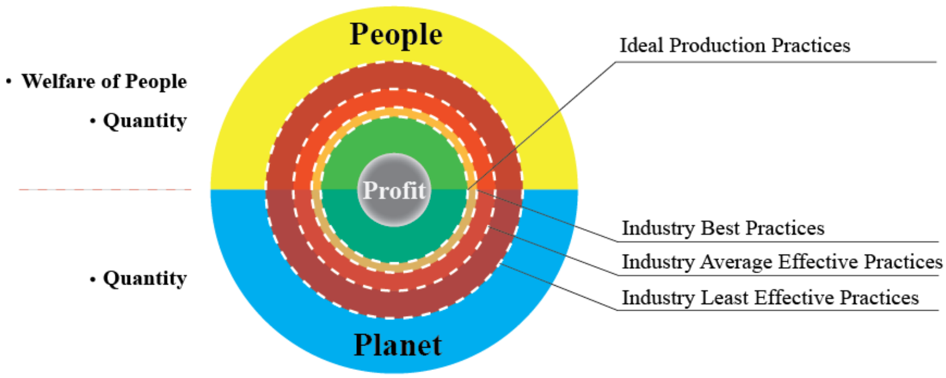
Figure 3.1: Various Production Practices and the Degree of Production Sustainability



Source: The Author

Logically, enhancing practices can result in greater sustainability. The challenge lies in the insufficient understanding of different practices that could obtain similar profits (product value after deducting tangible input costs) yet vary in their environmental and social consequences, as well as the methods for effectively advocating enhanced practices to industry leaders, highlighting the gaps in literature that have been identified. These variations in impact correspond to the conceptual sustainability levels illustrated in Figure 3.2. To put it more simply, there is little understanding of the quantifiable data regarding profit, resource usage, and labour quantity, as well as the data points related to production sustainability, including people's welfare. Therefore, it is crucial to carry out research focused on examining both quantitative and qualitative data related to the sustainability of the practice while also pursuing enhancements to further promote sustainability.

Figure 3.2: Conceptual Levels of Production Sustainability Across Different Practices



Source: The Author

3.2 Definition of Production Sustainability

The research aims to enhance production sustainability in the fashion industry. But what is production sustainability? Drawing on the Australian cotton industry, which defines sustainability as:

"Sustainability for the Australian cotton industry means running profitable and efficient businesses while creating environmental, economic, and social value. It also means being accountable to stakeholders for the industry's actions and impacts." (Australian Cotton Industry's Sustainability Working Group 2019)

This research defines production sustainability as follows:

Production sustainability means that every phase of the production chain operates profitably and efficiently while maintaining a balance with natural and human resources. It also means being accountable to stakeholders for the actions and impacts of the production process.

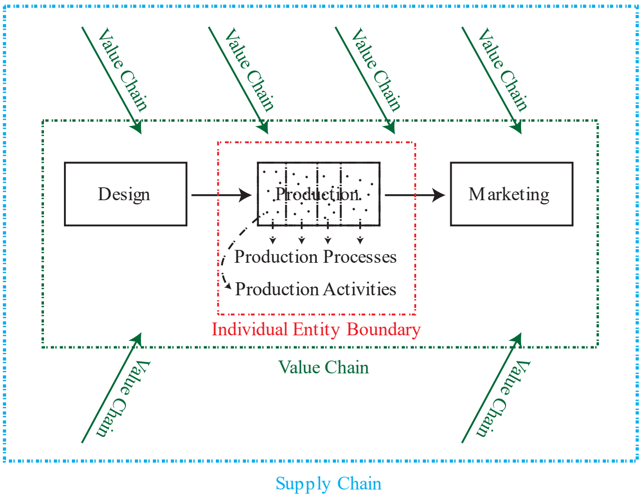
3.3 Research Question and Boundaries

This research addresses this challenge from an industrial perspective, drawing on the author's extensive experience and practical expertise, particularly from production management roles within the fashion industry, to develop feasible solutions to the problem. The overarching aim is to support informed decision-making within the industry to embrace more sustainable practices, in contrast to existing studies cantered on sustainability that primarily either highlight the significance of the problem or develop conceptual suggestions that fall short of actionable insights for the industry.

As discussed in the literature review (section 2.4.1), investigations into production should focus on evaluating both the tangible and intangible inputs and outputs that reflect the TBL framework, which encompasses land, labour, capital, entrepreneurship, value-added products, environmental emissions, and social impacts. The critical question is: "Which production data can be utilized, and how can it be applied to promote sustainable practices that will aid decision-makers within the fashion industry?"

This research question clearly delineates the production boundary within an individual entity to encompass production processes, as depicted in Figure 3.3.

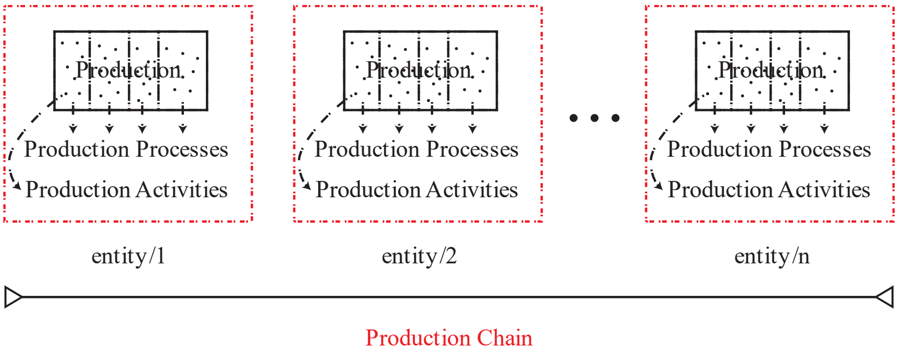
Figure 3.3: Individual Enterprise Production Boundary



Source: The Author

However, production in the fashion sector involves multiple entities and sustainable production means all entities operating profitably and productively while balancing natural and human resources. Hence the boundaries are also defined from a production chain perspective, as illustrated in Figure 3.4

Figure 3.4: Production Chain Production Boundary



Source: The Author

The delineated boundary primarily encompasses the production processes, inputs, and outputs, explicitly excluding:

- The production of accessories, which includes packaging, buttons, zippers, and fabric embellishment techniques such as beading, embroidery, and bonding, all of which are integral to the value chain but are hereby omitted from the investigative domain.
- The transportation and warehousing functions are also outside the remit of this examination.

3.4 Research Scope and Aim

Fashion, as a broad concept, encompasses clothing, footwear, headwear, leather goods, perfumes, and cosmetics (Brun et al. 2008; Macchion et al. 2015). Consequently, the fashion industry includes various sectors such as the clothing (or garment/apparel) industry, the footwear industry, the headwear industry, the leather industry, the perfume industry, and the cosmetics industry. Given the time constraints, conducting research across such a broad area is challenging. Therefore, narrowing the scope to the garment sector is a sensible strategy, as this sector has the most significant and substantial climate impact compared to other sectors within the broader fashion industry (Quantis, 2018).

The scope is further refined to focus on cotton clothing production, as clothing production involves intricate and multidimensional processes that vary based on the materials used. However, the experience and knowledge gained from investigating cotton clothing production are expected to lay a foundational understanding that can later be expanded or adapted to address a wider array of materials and processes.

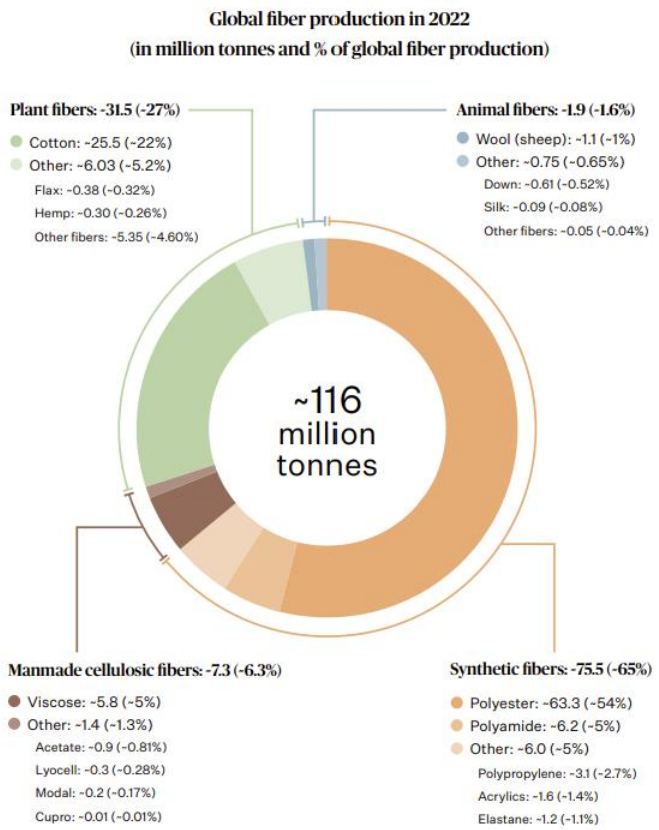
The decision to focus on cotton for clothing production is based on four key reasons:

First, the production techniques for all types of fibres are rooted in those originally developed for cotton, the most ancient fibre in the history of garment-making. Cotton clothing production serves as the foundational cornerstone for the manufacture of all categories of garments, holding a significant position within the industry. Thorough documentation and clarification of the cotton clothing production processes thus becomes instrumental in enhancing our understanding and interpretation of the manufacturing processes for other fibre varieties.

Second, there is a notable absence of thorough, analytical investigations within textile production, as pointed out by various studies (Joze et al. 2023; Moazzem et al. 2021; Sandin et al. 2019a; Tiwari and Jana 2021). Sandin and colleagues (Sandin et al. 2019) attribute this gap to the limited understanding of production processes. Examining the entirety of cotton garment production, from the seed to the finished product, is a pivotal approach in bridging this knowledge gap, as presented in chapter 5.

Third, Cotton clothing production embodies the broader expanse of garment manufacturing, surpassing 70% of the overall production volume when cotton and cotton/polyester blend clothing are considered together, given that their respective manufacturing processes are akin, with the most crucial variance identified at the fibre production stage. According to the Materials Market Report, in 2022, a total of 116 million tons of fibres were produced. The major materials used in clothing production were cotton and polyester, which accounted for 76% of all materials used. Cotton accounted for 22% with a production of 25.5 tons, while polyester accounted for 54% with a production of 67 million tons. These fibres find their primary utilization in textile industries, specifically in the clothing industry. (Textile Exchange 2023). Figure 3.5 presents the global fibre production volume status in 2022.

Figure 3.5: Global Fibre Production in 2022



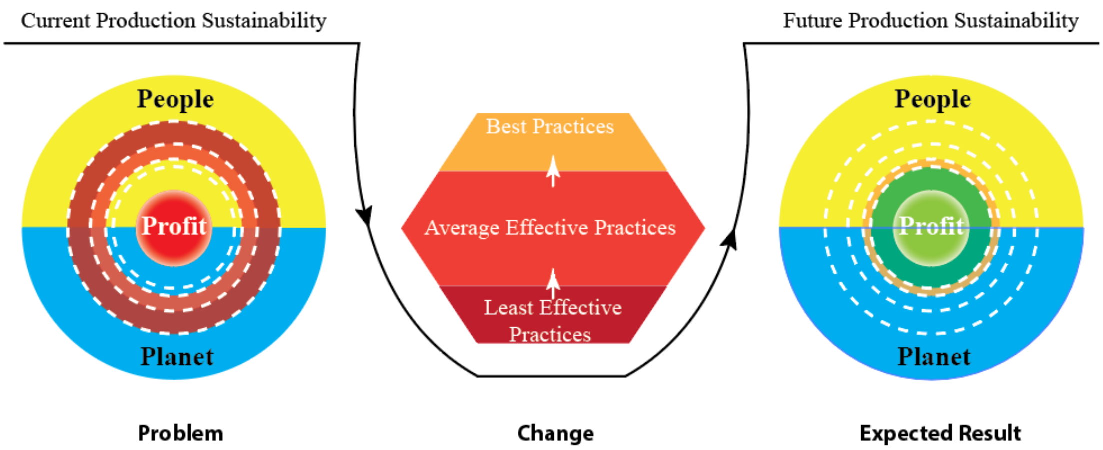
Source: Textile Exchange based on data from CIRFS, FAO, ICAC, IVC, IWTO, Maia Research, and its own modelling. Note: This chart includes recycled fibers. Other animal fibers included here are alpaca, angora, camel, cashmere, guanaco, llama, mohair, vicuna, and yak. Other plant fibers included here are jute, coir, sisal, abaca, ramie, kenaf, kapok, and agave. (Textile Exchange 2023)

Finally, practical time constraints dictate the need for a focused scope to ensure that the research can be conducted thoroughly and yield actionable results within a defined period. The aim of this study is to enhance the sustainability of production by advocating for advanced practices within the cotton apparel sector.

3.5 Problem-solving and Decision-making

The research's aim entails transitioning from current production practices to a more future-oriented approach by improving less effective methods to more efficient ones and ultimately to best practices, as illustrated in Figure 3.6. The "Change" indicates the solution to the central challenge of transitioning from current production sustainability to future sustainability. Current Production Sustainability refers to a scenario where production profits are often achieved by using more resources than necessary or available best practices within the industry, engaging less responsibly with people, or both. The degree to which this occurs can vary depending on the specific practices employed. Future Production Sustainability is characterized by achieving production profits through the use of top industry standards in resource management and responsible engagement with people.

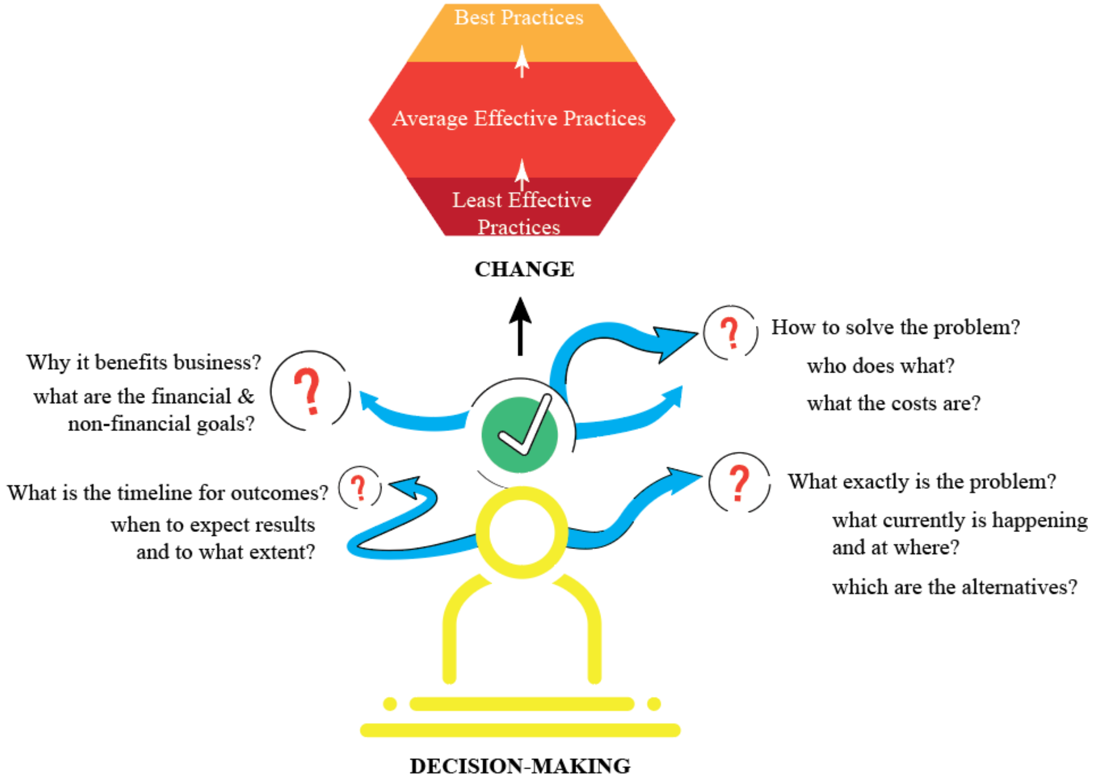
Figure 3.6: Enhance Production Sustainability



Source: The Author

Achieving these improvements necessitates robust decision-making support. Business decision-making primarily focuses on solutions (Nutt 1984), which are typically designed to address the questions of what, why, when, and how, known as the 3W1H technique, a term also interpreted as 5M/7M technique (what, where, who, why, when, which, where) (Čančer and Mulej 2013). Believed to have originated from the journalism industry, these questioning techniques are the most widely used rationale methods in decision-making processes across various fields. Therefore, the decision-making considerations for promoting more sustainable practices involve evaluating solutions that address what, where, who, why, when, and which, as illustrated in Figure 3.7. This aligns with the author's experience and observations in fashion industry production management.

Figure 3.7: Decision-making Consideration for Changes



Source: The Author.

Note: The decision-making icons are commercially usable and authorized from https://www.vecteezy.com/.

Therefore, the overarching aim of this research can be divided into specific, actionable goals that aid in formulating solutions to address these questions. These solutions can then be presented as change proposals for evaluation in the decision-making process.

3.6 System and Design Thinking

This research argues that in the context of cotton clothing production, solutions to specific sustainability problems related to the production process, phase, or chain - whether at the level of an individual enterprise, sector, or industry - should be formulated in consideration of a holistic production system that includes all participating entities. In the current industrial age, producing clothing from raw material to finished garments typically constitutes a global endeavour by a wide range of organisations for parts of the work. This is particularly the case for clothing intended for economically advanced nations, such as North America, Europe, and Australia, where the design process typically remains localized, while most of the production occurs in developing regions of Asia and Africa. Additionally, this industry employs a significant number of workers from various backgrounds, and the diversity of materials and techniques adds to the complexity of the field.

It is therefore essential to address this real-world challenge with a design thinking approach, in which methods are carefully crafted and outcomes are effectively anticipated to minimize the potential impacts of changing one element on other parts of the system (Schein and Schein, 2016), across various levels including process, organization, supply chain, or industry. For example, an organization may appear to have achieved sustainability when assessed in isolation; however, it could exert pressure on its supply chain partners who engage in unsustainable practices to uphold the profitability of the business. Therefore, adopting a production system perspective is crucial for the industry's transformation towards ultimate sustainability, as it discourages changes that may appear to enhance sustainability within a limited scope, such as an individual enterprise, but ultimately violate other stakeholders' benefits and cause deterioration for the industry as a whole.

System and design thinking promotes collaborative and transparent among businesses, which must rely on a collective understanding that is especially vital for upstream enterprises. For instance, in the context of price negotiations, instead of solely focusing on price competition, upstream companies can actively involve themselves in the pricing process and collaboratively reach a consensus on a reasonable price that upholds a fair profit margin for downstream enterprises without resorting to unsustainable practices. However, this shared understanding is limited, hindering practitioners from promoting alternative practices to address problematic ones observed in practice. This limitation, identified as a gap in the cotton clothing production literature, inspired this research.

3.7 Research Goals

The research goals should therefore focus on a problem-solving process that appeals to decision-makers while also considering the sustainability of the entire production system. Accordingly, two goals are established as follows:

Goal 1: establish complete TBL production datasets (TBLPDs) for individual organisations that effectively showcase practices while being capable of analytically identifying and monitoring areas of TBL sustainable opportunities, contributing to the development of proposals for decision-making on advanced practices. Achieving this goal requires two key objectives:

a) Designing an Production Input-Output Data Framework (PIODF)

b) Collecting data using the PIODF

The proposals intended must convincingly demonstrate the financial viability of implementing advanced practices. The TBL sustainable opportunities encompass, but are not limited to, minimizing resource inefficiencies, reducing excessive production waste, and enhancing social responsibility. Successfully accomplishing Goal 1 would establish a robust foundation for strategic planning and day-to-day management decisions within individual enterprises in the production chain. Once Goal 1 is attained, the progression to Goal 2 can be initiated.

Goal 2: Compile individual TBLPDs and integrate them into cohesive datasets that allow for distinguishing between the best, average, and least efficient production practices, while also offering insights to enhance less effective practices toward more advanced ones.

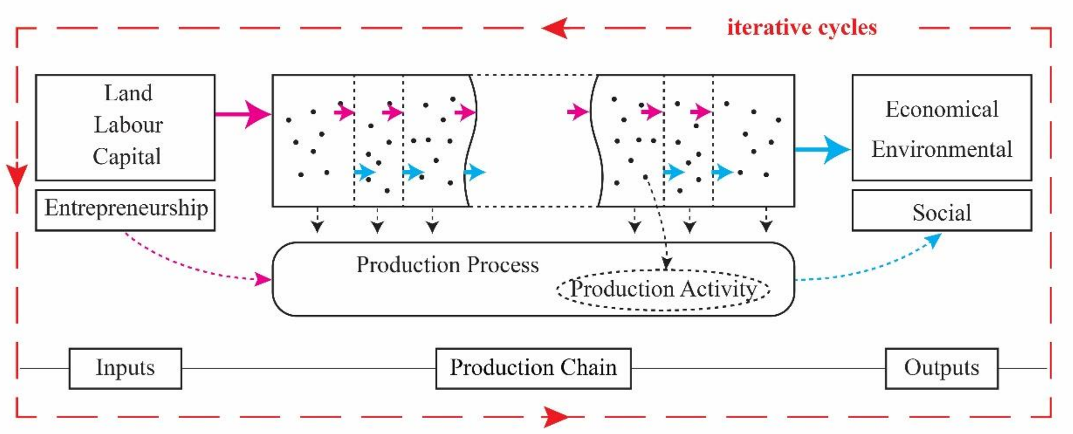
Achieving Goal 2 would steer and support individual organizations with essential insights towards advancement, and potentially shaping industry governance and policy formulation towards a more sustainable future for cotton clothing production.

These goals and objectives highlight the critical actions towards transitioning to sustainable production. The first step is to explore or develop methods for establishing the IOPD, as detailed in the subsequent section.

3.8 Research Methods

As outlined in Sections 2.4.1 and 2.4.2, investigations of production for sustainability should concentrate on assessing both tangible and intangible inputs and outputs which includes land, labour, capital, entrepreneurship, value-added products, environmental emissions, and social consequences, using a bottom-up IO approach. Iterative cycles of examining these elements will help build knowledge and refine methods to achieve the anticipated outcomes. This concept is illustrated in Figure 3.8.

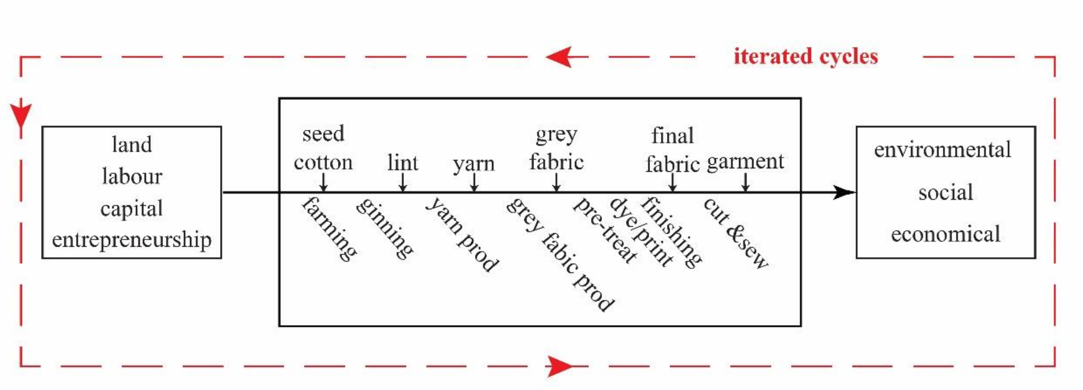
Figure 3.8: Production Examination Iterative Cycles



Source: The Author

In relation to clothing production, literature typically categorizes the production of clothing into four primary phases: fibre production, yarn production, fabric production (which includes wet processing), and garment production. (Muthu 2020; Moazzem et al. 2021; Sandin et al. 2019a) The industry, however, functions within a supply chain model where suppliers benefit from their respective segments of the supply, involving intricate and diverse processes that differ according to the materials employed. In the production of cotton clothing, the process begins with cotton seeds and continues through to the finished garments. It starts with cotton farming, followed by cotton ginning, then advances to yarn production and grey fabric production. The process then moves on to fabric dyeing, printing, and finishing, ultimately culminating in the final garment production, as shown in Figure 3.9. Iteratively evaluating these processes and elements is anticipated to enhance the understanding of cotton clothing production and to aggregate the requisite data that is critical for informing decision-making.

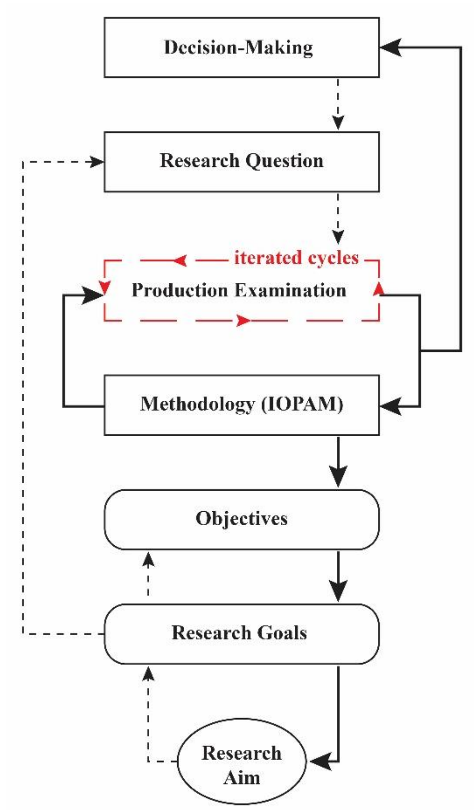
Figure 3.9: Cotton Clothing Production Examination Iterative Cycles



Source: The Author

However, this endeavour requires a thorough bottom-up Input-Output (IO) methodology, and an Input-Output Production Analysis Methodology (IOPAM) is currently being developed. This IOPAM is formulated to achieve the overarching research objective of improving production sustainability through the facilitation of informed decision-making. A conceptual model for developing IOPAM is shown and briefly described in Figure 3.10.

Figure 3.10: Conceptual Framework for Developing IOPAM



Process:

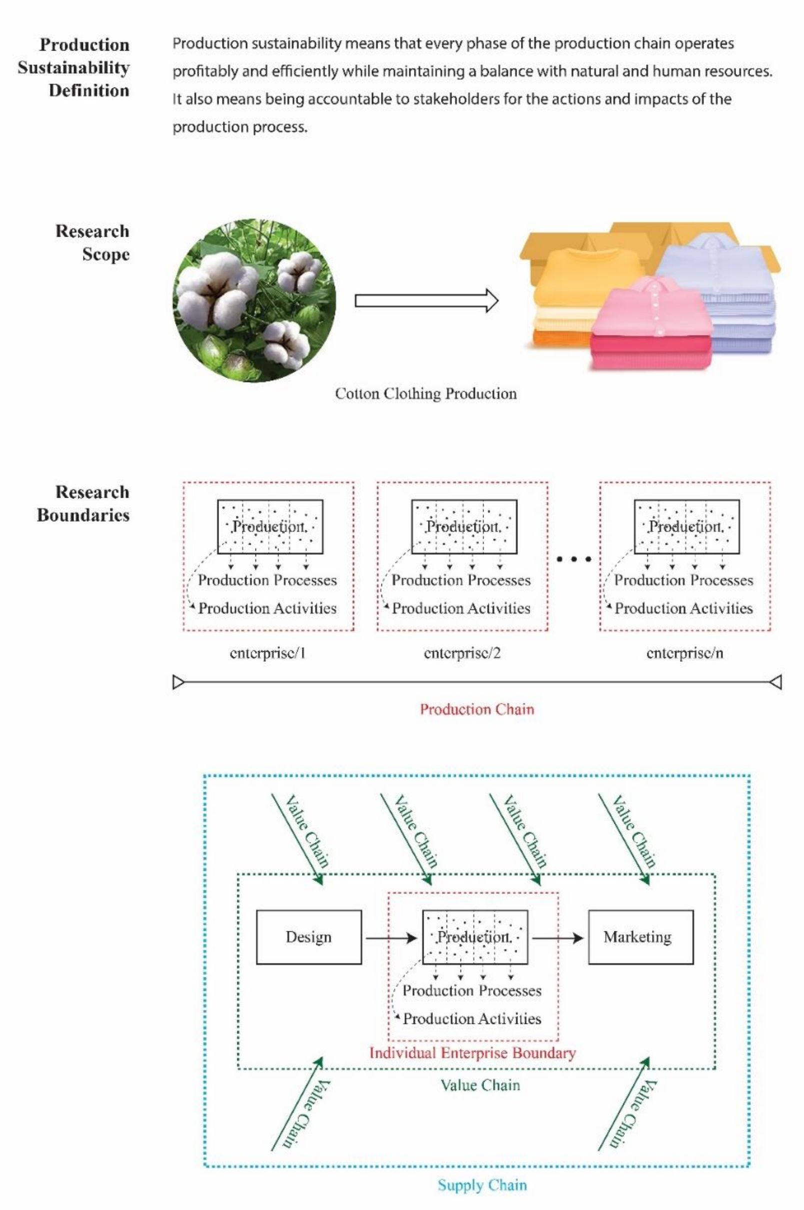
1. The research aims to improve production sustainability.
2. The research aim helps refine the research goals.
3. The research question connects decision-making with the research goals.
4. The research goals refine the research objectives.
5. Production analysis is conducted to answer the research question and lay the foundation for developing IOPAM, through an iterative process.
6. Ongoing progress achieves objectives and can be applied to specific scenarios to support decision-making.
7. Achieving the objectives leads to accomplishing the goals and, ultimately, the research aim.

Source: The Author

3.9 Research Frameworks

Up to this point, all relevant aspects of a complete research project aiming for enhancing production sustainability of the clothing sector - from the initial motivation to problem framing, solution development, developing methodology, and anticipation a transformation towards overarching aim - have been thoroughly examined and encapsulated in frameworks that visually illustrate all research elements relevant for maintaining a focused approach for achieving results. Figure 3.11 illustrates a framework outlining the research boundaries and scope, along with the definition of production sustainability.

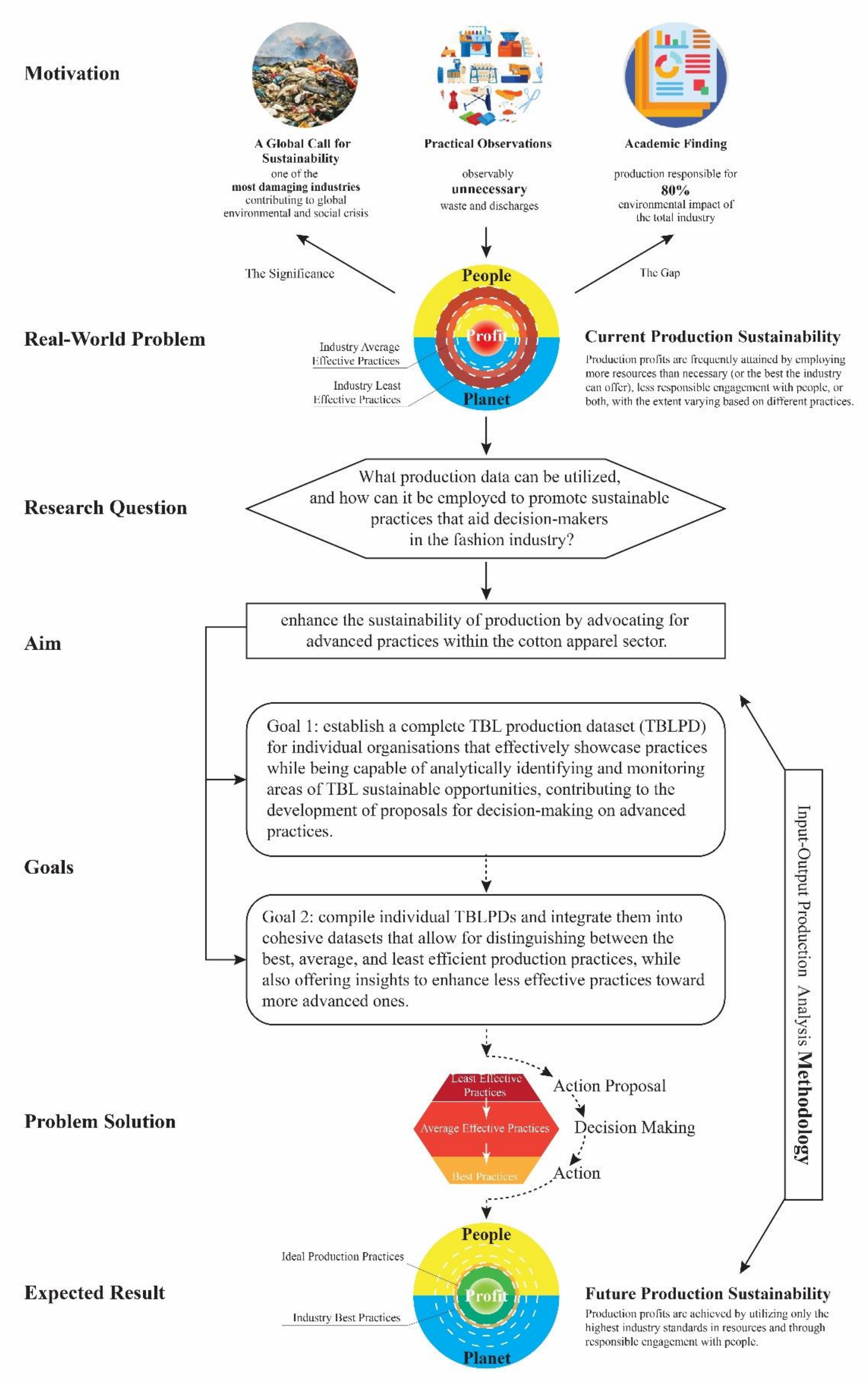
Figure 3.11: Research Scope and Boundary



Source: The Author

Figure 3.12 presents a comprehensive Research Framework that outlines a pathway for achieving a completed research project.

Figure 3.12: Comprehensive Research Framework



Source: The Author

3.10 Ethical Considerations

There are two main ethical concerns for this research. One involves protecting participating organizations or individuals from the risk of a) having their business data misused by competitors, media outlets, legislative bodies, or parties with vested interests; b) facing criticism regarding their environmental and societal practices. The other relates to the ethical conduct of this research. For the former, strategies must be implemented to tackle this issue; however, it is currently not relevant at this stage. For the latter, we ensured complete transparency regarding our research intentions and potential publications. Ethics approval (UTS HREC Reference Number ETH22-7194) for all aspects of the study, including both online and face-to-face interviews and field studies with Chinese industry experts, was secured from the university's Ethics Committee, ensuring compliance with institutional and ethical research standards. Lastly, the content of this research underwent thorough examination to ensure strict compliance with the first ethical consideration.

3.11 Research Data Storage

While data storage is typically the final step of the research design, it is important to note that from the beginning of the research process, data storage was a planned and integral aspect. In order to address the requirements of research transparency and publishing, two distinct data management plans were created. These plans form separate components of the overall research data management strategy and were stored in the Stash system.

The first data management plan, namely Assessing Triple Bottom Line Sustainability of Cotton Clothing Manufacturing: Advancing an Input-Output Production Analysis Methodology _ Part 1 of 2 _ Open Data, focuses on the management and storage of open data, which is intended for unrestricted access, usage, and redistribution by the public. This data consists of non-sensitive, non-personal information that can be utilized by individuals for various purposes such as research, analysis, application development, and decision-making.

The second data management plan, namely **Assessing Triple Bottom Line Sustainability of Cotton Clothing Manufacturing: Advancing an Input-Output Production Analysis Methodology** _ Part 2 of 2 _ Confidential Data, pertains to the handling and storage of sensitive data, including interview recordings. This data necessitates special protection due to its sensitive or confidential nature. Measures are implemented to ensure the confidentiality, integrity, and availability of this data, adhering to legal and ethical requirements. Security protocols, such as access controls, encryption, and anonymization techniques, are employed to safeguard sensitive information. These measures and security protocols are well explained to participants through Participant Information Sheet and consent is obtained afterwards.

By having separate data management plans for open data and sensitive data, the research endeavours to appropriately address the unique considerations and security requirements associated with each data type. This approach ensures that the research data is effectively managed and stored in accordance with the nature of the information, promoting transparency, accessibility, and security throughout the research process.

Chapter 4 An Input-Output Production Analysis Methodology

Chapter 3 (section 3.8) emphasized the rationale for developing the bottom-up IOPAM, particularly due to the inadequacy of current IO analysis in delivering a comprehensive examination of production at the micro level, especially across the entire production chain, as discussed in the literature review (section 2.4.2). This IOPAM is still under development and serves as a key element of ongoing initiatives; however, the advancements achieved thus far have attained a crucial milestone that the forthcoming steps should build upon, as part of the envisioned PhD phase.

This chapter outlines the pragmatic epistemology that underpins and the IOPAM and its development framework, specifying the methodological components, including input and output indicators, methodological tools, data collection methods, production analysis techniques, along with its anticipated advancements.

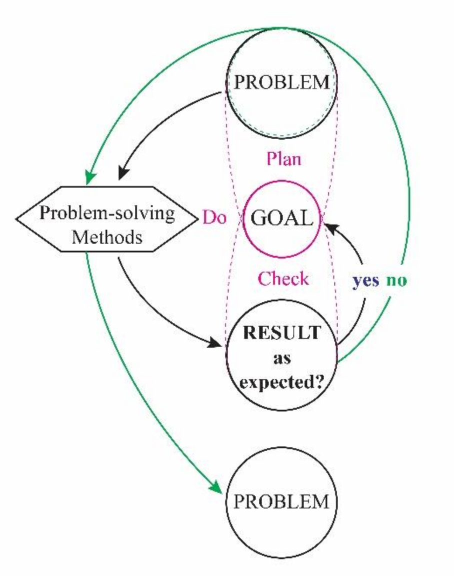
4.1 Pragmatic Epistemology

4.1.1 Empirical Approach to Problem-Solving

A problem is considered to be “an undesirable result of a job” (Suárez-Barraza and Rodríguez-González 2018). Problem-solving is to turning the undesirable result to a desirable outcome and is a skill often attributed to individuals and is closely linked to their cognitive disposition, drawing on the problem solver's knowledge and experience (Simon 1973; Mohaghegh and Furlan 2020; Laureiro-Martínez and Brusoni 2018; Liljedahl and Cai 2021). This knowledge and experience function similarly to what Herbert A. Simon (1973) described as “long-term memory” or as "data" in the context of grounded theory (Glaser and Strauss 1967). The author's extensive experience in the fashion industry, particularly in production management, serves as a crucial foundation for the development of the IOPAM. Production management focuses on addressing ongoing and immediate production issues to enhance efficiency throughout the entire production chain. Desired outcomes include streamlined production processes, problem resolution, improved product quality, and cost reduction. To execute production management effectively, a diverse range of skills and capabilities is essential. These include a comprehensive understanding of production processes, such as garment construction, work and material flows, specific responsibilities and tasks within the production chain, and their estimated outcomes. Effective relationship management with factories is vital to navigate and overcome various challenges that may arise. Communication proficiency, especially in bridging time zones and language barriers, is crucial for success in the global production context. Accurate sales and inventory forecasting, meticulous validation and documentation of production activities, and the ability to anticipate potential issues are all essential skills. Additionally, adept negotiation skills are necessary when dealing with a wide array of stakeholders with unique demands.

The production knowledge gained through these experiences provides the author with the "professional competence" necessary to identify a valid problem-solving approach for the problem this research aims to address. However, explaining the rationale behind this validation can be challenging, as John Adair (2007) notes that "decision making and problem solving are so closely tied to specific types of information or knowledge - areas of professional competence - that it is difficult to consider them in the abstract." Nevertheless, the pragmatic problem-solving process involves identifying specific problems and goals, and exploring methods focused on achieving those goals. This approach is similar to the decision-making process that addresses the 5M/7M framework (what, where, who, why, when, which, where) (Čančer and Mulej 2013) and integrates the Plan-Do-Check cycle, an action-oriented philosophy detailed in the next section, into every activity until the problem is satisfactorily resolved. Figure 4.1 depicts a general pragmatic problem-solving method that the author has successfully applied in both production management and personal life.

Figure 4.1: Pragmatic Problem-solving Method



Source: The Author

4.1.2 Action Oriented Philosophy: Plan-Do-Check

Inspired by John Adair (2007), who observes that "decision making and problem solving are so closely tied to specific types of information or knowledge - areas of professional competence - that it is difficult to consider them in the abstract," the author similarly finds that problem solving and a Plan-Do-Check (PDC) action oriented philosophy, are so integral to achieving satisfactory outcomes in problem-solving, also areas of professional competence, and it is equally challenging to consider them in isolation from practical application.

Drawing from the author's experience, nearly every successful endeavour in both work and life involves activities that incorporate the Plan-Do-Check cycle, while most setbacks or sorrows have occurred in its absence.

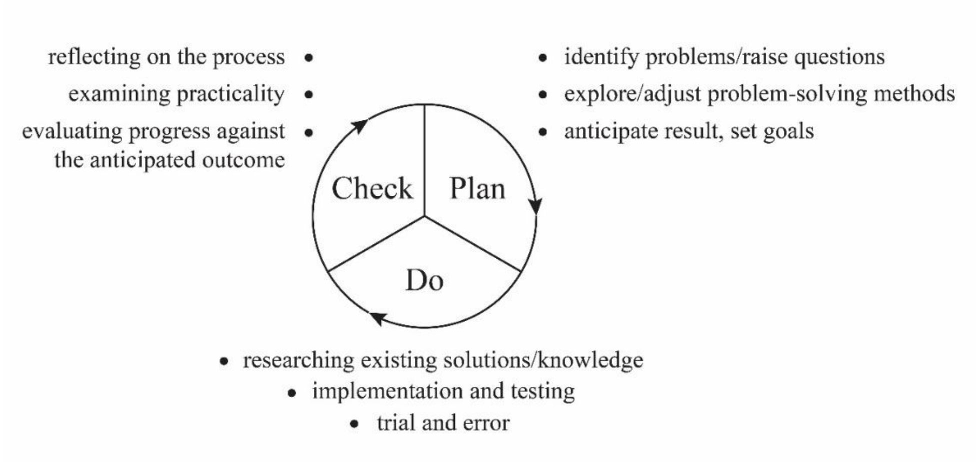
The "Plan" stage involves identifying the problem, setting goals, anticipating outcomes, and developing strategies to achieve the desired results. This stage is deeply rooted in the practitioner's knowledge and experience, or professional competence when addressing work-related challenges. his expertise is crucial in setting valid and achievable goals, which ultimately determine the effectiveness of the Plan-Do-Check endeavour.

The "Do" stage entails executing preconception methods through researching existing knowledge, implementing solutions, and engaging in trial and error. This phase is thus categorized into three key activities: "researching existing solutions/knowledge," "implementation and testing," and "trial and error."

The "Check" stage involves evaluating the outcomes of the "Do" phase against the expected results, reflecting on both the successes and shortcomings of the process, and assessing practicality in terms of gains and losses across various dimensions. Activities in this stage include "reflecting on the process," "examining practicality," and "evaluating progress against the anticipated outcome." Figure 4.2 visually represents this cycle, with its iterative nature driving continuous improvement and serving as a key element in effective problem solving.

A crucial aspect of the PDC cycle is seeking and evaluating feedback, which often uncovers constraints and limitations. Feedback encompasses more than just written or verbal responses; it also includes non-verbal cues from the audience, such as actions or facial expressions that reflect their level of understanding and engagement. For instance, if the audience appears confused when receiving a message, it may indicate the need to restructure the communication to better align with their cognitive framework. Similarly, if a decisionmaker does not respond to a proposal, it suggests the necessity of aligning the proposal more closely with their thought processes or simplifying it to fit their available time and attention. Understanding decision-makers and effectively communicating with them are critical steps toward achieving any real-world objectives. These insights also help shed light on the disconnect between academia and industry.

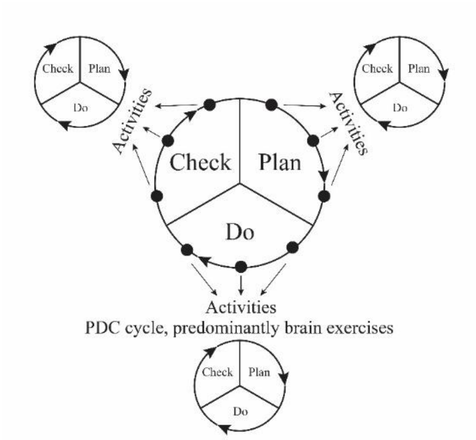
Figure 4.2 Plan-Do-Check (PDC) Cycle



Source: The Author

Another key aspect of the PDC cycle is that each activity within the "Plan," "Do," or "Check" stages encompasses its own complete PDC cycle. Initially, these cycles are primarily mental exercises, but some may require a combination of intellectual and physical efforts, as shown in Figure 4.3. This resonates with practical experience, underscoring the importance of ensuring that every action is driven by a clear purpose to support wise decision-making.

Figure 4.3 Plan-Do-Check within PDC



Source: The Author

Although the PDC is grounded in practical experience, it aligns with the sophisticated theoretical framework of the Plan-Do-Check-Action (PDCA) cycle. Both models emphasize the essential need to plan activities before execution and to perform checks afterwards, revealing a similar foundational thought process. Notably, the PDCA cycle, as shown in Figure 4.4, includes an 'Action' step absent in the PDC cycle, underscoring their distinct origins and applications. The PDC, an action-oriented philosophy developed by the author, originates from her experience in the fashion industry's bulk production, where the disposability of products necessitates a quick-response PDC cycle, in contrast to the more rigid PDCA cycle. The latter was initially implemented in the automotive industry, where the high costs associated with product disposal demand a more thorough approach. This difference underscores the distinct requirements and practices of each industry, therefore the divergence between the PDC and PDCA cycles.

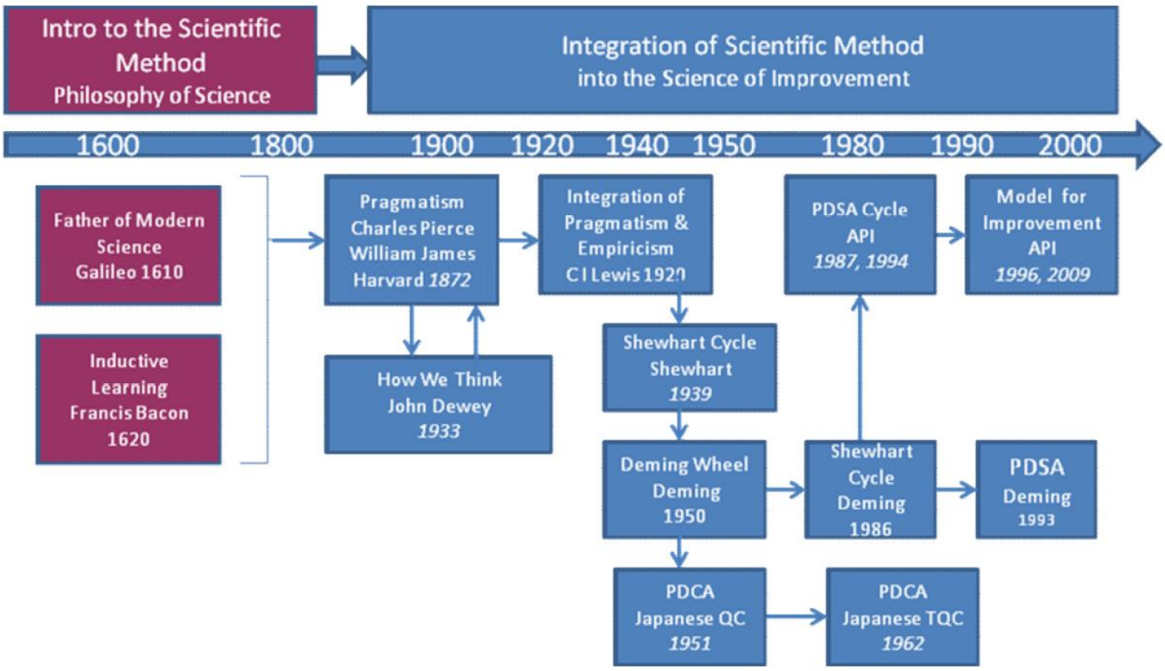
Figure 4.4: PDCA (Plan-Do-Check-Act)

Plan:	definition of a problem and a hypothesis about possible causes and solutions
Do:	implementing
Check:	evaluating the results
Action:	back to plan if the results are unsatisfactory or standardization if the results are satisfactory

Source: Evolution of the PDCA Cycle (Figure 6) (Moen and Norman 2009)

Figure 4.5 illustrates a timeline detailing the evolution of the PDCA cycle, originating from 16th-century modern science and inductive learning principles. It gained prominence after further development by Dr. W. Edwards Deming and underwent additional enhancements and refinements by Japanese industries, solidifying its status as a quality control tool. The PDCA cycle is underscored by Dr. Kaoru Ishikawa, who emphasized the importance of setting goals, targets, and methods during its planning phase (Ishikawa 1990; Moen and Norman 2009), a concept that validates the purpose of the 'Plan' stage in this Plan-Do-Check model.

Figure 4.5 Plan-Do-Check-Action (PDCA) Evolution



Source: Evolution of the Scientific Method (Figure 1) (Moen and Norman 2009)

Dr. Deming also further refined his Plan-Do-Check-Act (PDCA) concept into the Plan-Do-Study-Act (PDSA) cycle, as depicted in Figure 4.6.

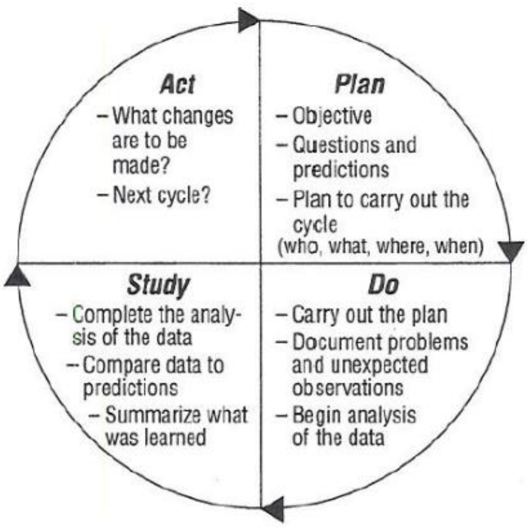


Figure 4.6: Deming 1994 PDSA (Plan-Do-Study-Act)
Source: Evolution of the PDCA Cycle (Figure 9) (Moen and Norman 2009)

4.1.3 Result-driven Problem-Solving

Problem-solving approaches are commonly categorized into two types: intuitive problem-solving and systematic problem-solving. Intuitive problem-solving is characterized by a focus on addressing the symptoms or immediate manifestations of a problem. It involves finding quick and practical solutions that alleviate the immediate issues without necessarily delving into the underlying causes. Systematic problem-solving involves a more methodical and analytical approach. It emphasizes the diagnosis and identification of the underlying causes of a problem that involves data gathering, analysis, and the use of structured problem-solving frameworks or methodologies (Mohaghegh and Furlan 2020).

Indeed, significant industrial problems require a systematic problem-solving approach that effectively breaks down the main issue into manageable segments. A results-driven strategy provides clear purpose and direction, ensuring that each segment contributes toward the desirable results, ultimately leading to optimal overall outcomes. This strategic alignment guarantees that efforts are consistently and effectively focused on achieving the ultimate goal, as illustrated in Figure 4.7.

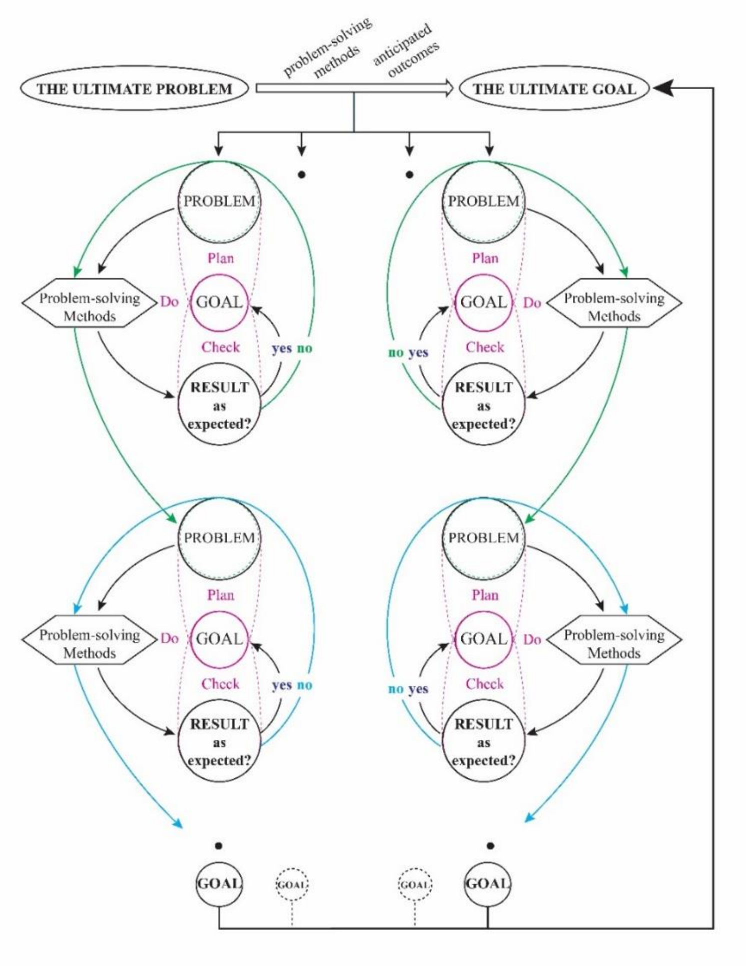
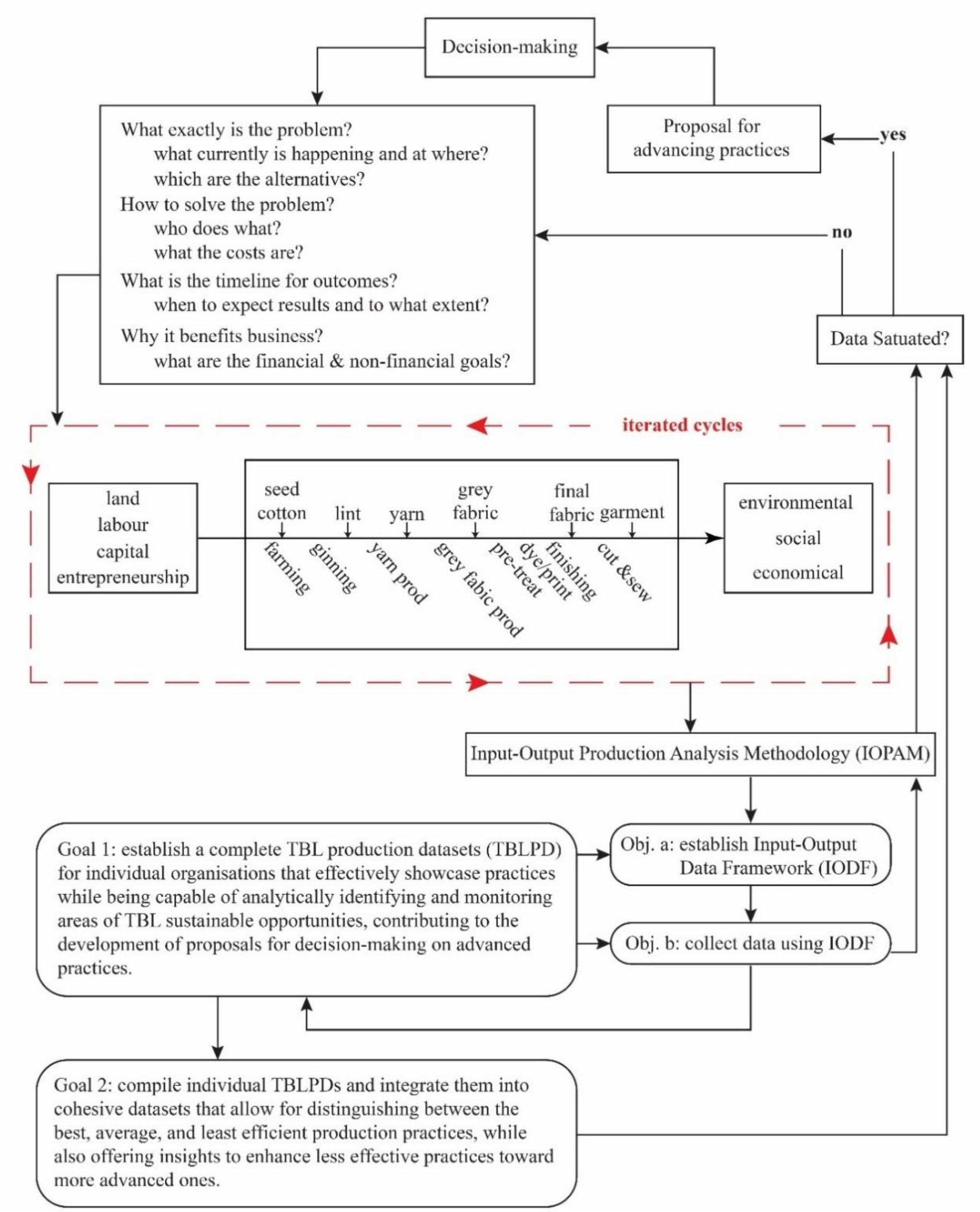


Figure 4.7 Pragmatic Result-driving Problem-solving Method
Source: The Author

4.1.4 Data Driven through Result-driven Problem-solving Strategy

When evaluating cotton clothing production, where problem-solving efforts focus on making positive changes and boosting sustainability through improved practices supported by production data and analysis, a results-driven problem-solving strategy is crucial. This approach guides the formulation of the IOPAM, as shown in Figure 4.8, aligning with the conceptual framework for IOPAM development (Section 3.8, Figure 3.10).

Figure 4.8: Result-driving Problem-solving for Development of IOPAM



Source: The Author

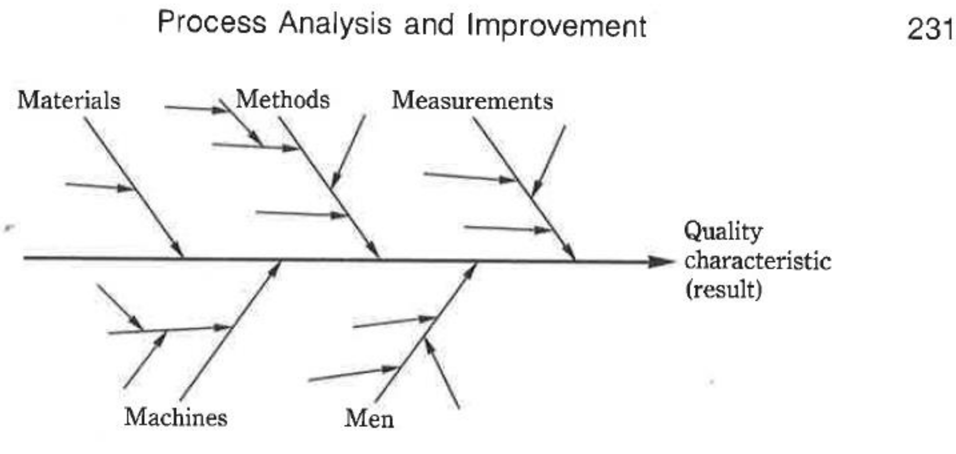
The initial outcome of the IOPAM development process is the establishment of the PIODF (Objective a). Achieving the PIODF marks a pivotal milestone in advancing IOPAM, as it will serve as the foundation for future initiatives. The PIODF is specifically designed to ensure that data collection and compilation align with the TBLPD (Goal 1), providing an accurate representation of practices and enabling the analysis of sustainability opportunities. Therefore, the iterative cycles of examining production elements incorporating a thorough analysis of the cotton garment manufacturing process, which ranges from seeds to the finished product (elaborated in Chapter 5), illustrate the industry operations that consist of up to 100 processes across various producers. Following this, a conceptual assessment of cotton shirt production is performed, with the purpose of evaluating the global production impact of Australian cotton (discussed in Chapter 6), ensuring that data collection is practical and that the analysis directly relates to TBL, thereby identifying potential opportunities.

4.2 Methodological Indicators

4.2.1 Inputs Indicators

Section 3.8 emphasized that production factors encompass both tangible inputs, encompasses land, labour, and capital, and intangible inputs, including entrepreneurship. These factors align with the subjects explored in production-related studies of the industry, such as the total quality control approach known as the elite 5Ms framework (Men, Materials, Machines, Methods, and Measurements), as shown in Figure 4.9.

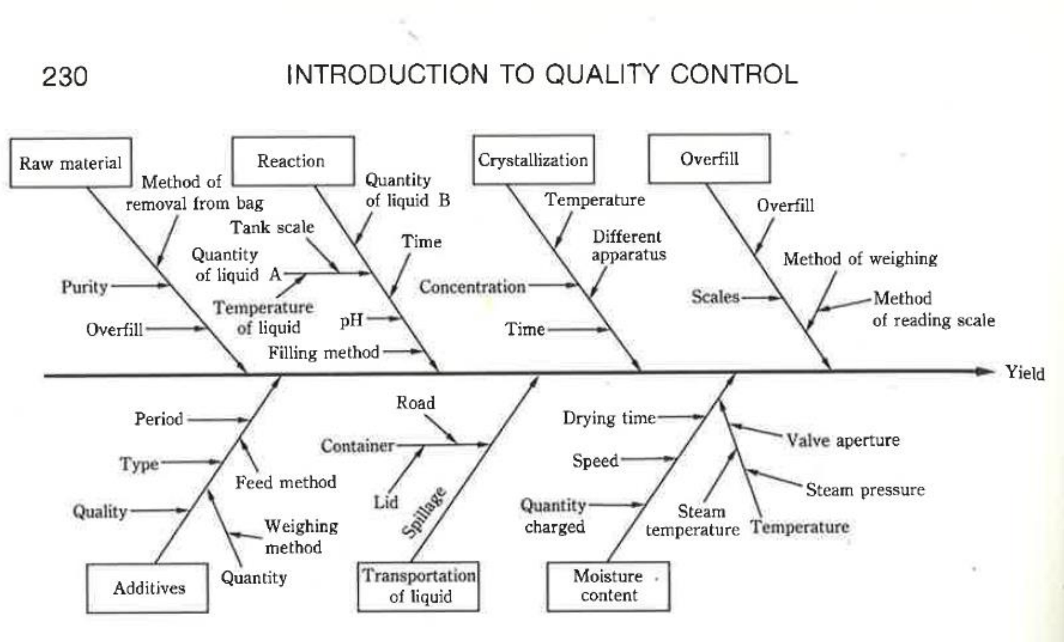
Figure 4.9: Quality Controlling Processes – The 5 Ms



Source: Introduction to Quality Control (book, figure 4.4)

The 5Ms framework, also recognized as the fishbone or cause-and-effect diagram, was originally developed by Dr. Kaoru Ishikawa to tackle quality issues in manufacturing. He emphasizes the flexibility of his diagrams with illustrative examples, demonstrating their suitability for various applications. One example, as Figure 4.10, showcases how the specific elements within the 5Ms are identified to address a particular quality challenge. (Ishikawa 1990)

Figure 4.10: Example of 5Ms Application by Dr. Ishikawa

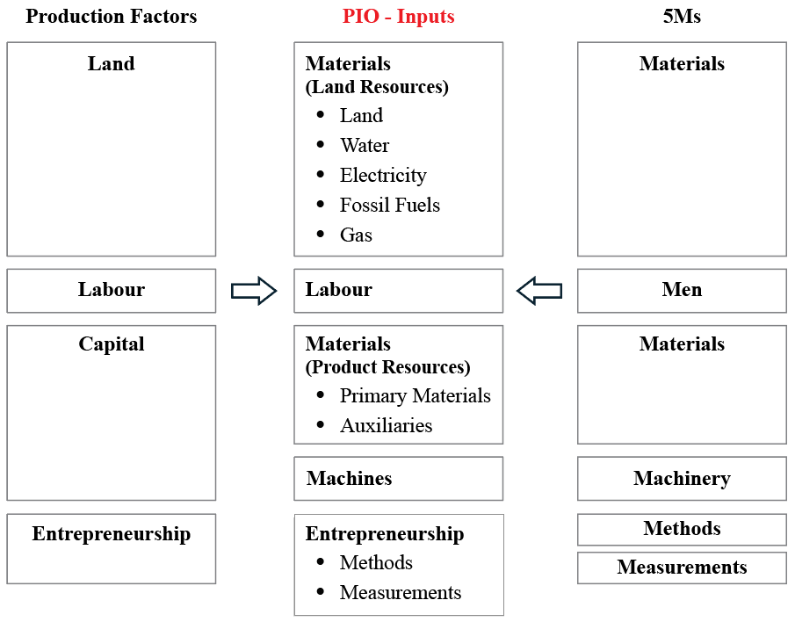


Source: Introduction to Quality Control (book, figure 4.3)

In Chinese manufacturing sites, the 5Ms framework is widely recognized and used by practitioners. This trend highlights the extensive acceptance and importance of the 5Ms construct in the manufacturing industry, and its ability to adapt to diverse operational environments.

Through the iterative process, the factors of production are combined with the 5Ms to create inputs that more accurately reflect the production inputs-outputs (PIO - Inputs) phenomenon, as illustrated in Figure 4.11. Despite these adjustments, the PIO - Inputs essentially remain production factors, albeit in a modified form. Consequently, the input indicators include Materials (land resources such as land, water, electricity, fossil fuels, gas; and product resources like primary materials and auxiliaries), Labour, Machines, and Entrepreneurship.

Figure 4.11: PIO - Inputs



Source: The Author

Each PIO-Inputs is defined as follows:

- Materials
  Land Resources: Represents natural resources such as land, water, electricity, fossil fuels, and gas, all of which are derived directly or indirectly from the land.
  Product Resources) Includes primary materials and major auxiliaries that have the potential for significant impact.
- Labour: Refers to the human workforce essential for production.
- Machinery: Corresponds to tangible assets acquired through capital investment, such as tools, machinery, and equipment used in production, thus related to "Capital."
- Methods and Measurements are both linked to "Entrepreneurship," necessitating qualities like innovation, decision-making, and managerial skills. "Methods" encompass strategies for efficient production, while "Measurements" focus on data collection and analysis for performance evaluation and strategic decision-making.

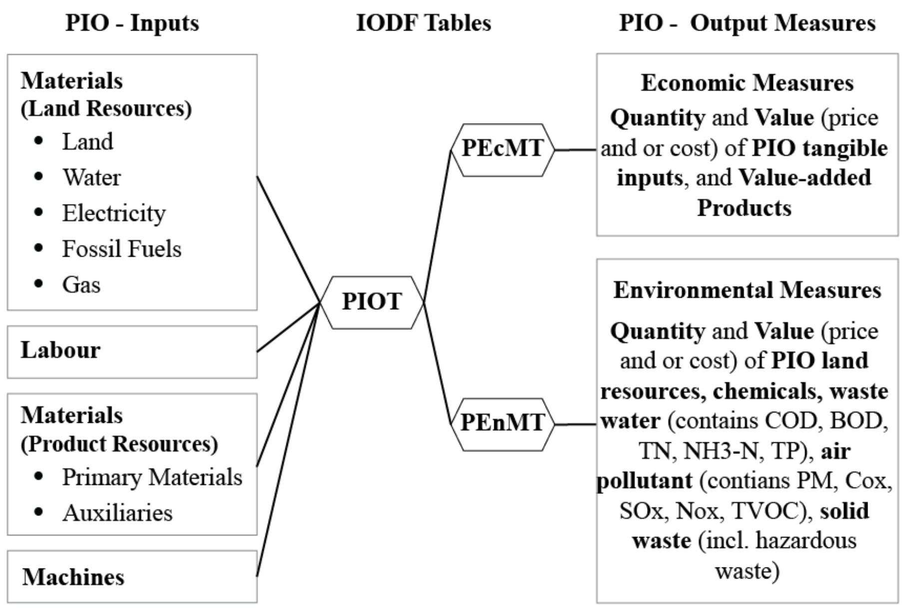
4.2.2 Outputs Indicators

Section 3.8 elaborated that production outputs include both the quantitative results of value-added products and production discharges, along with the qualitative outcomes linked to social impacts. Value-added products represent the direct economic output of the production processes, while production discharges have garnered significant attention yet remain challenging to accurately estimate through environmental assessment methods like LCA and footprint analyses of water, electricity, carbon, etc. Nevertheless, when combined with China's National Pollution Source Census, they contribute to the development of environmental output indicators that encompass chemicals, discharges of COD, BOD, TN, NH3-N, TP in wastewater, emissions of PM, COx, SOx, NOx, TVOC in the air, and solid waste, including hazardous waste. The qualitative outputs linked to social impacts, however, however, have not yet been examined due to time constrains, but most crucially, they require investigation in real-world contexts.

4.3 Methodology Tools

Some medium needs to be introduced to the PIO-Inputs and PIO-Outputs indicators. To achieve this, various tools have been developed. Currently, four tools have been established to support quantitative data collection and analysis: Production Input-Output Flowcharts (PIOFs, Tool 1), Production Input-Output Tables (PIOTs, Tool 2), Production Economic Measures Table (PEcMT, Tool 3), and Production Environmental Measures Table (PEnMT, Tool 4). PIOTs capture production data related to PIOFs and supply critical information to both PEcMT and PEnMT, effectively linking practices with TBL measures, as illustrated in Figure 4.12.

Figure 4.12: IOPAM Quantitative Components



Source: The Author

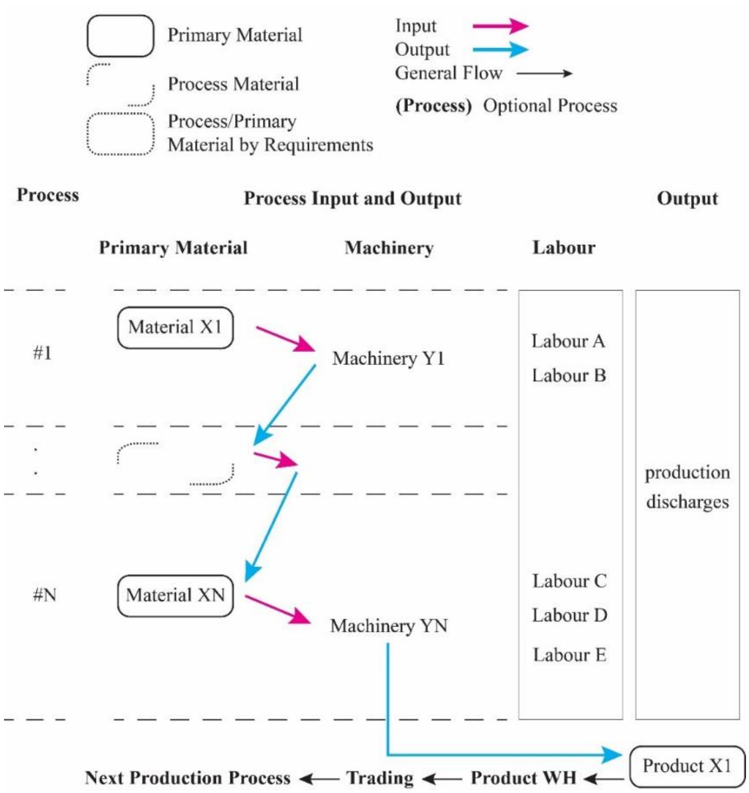
Entrepreneurship influences the effectiveness of production methods and measurements, as well as the social dimensions of the TBL, which have not been explored due to limitations in time. As a result, Production Social Measures (Tool 5) and Entrepreneurship Measures (Tool 6) are planned for additional improvement.

Tool 1: Production Input-Output Flowcharts

PIOFs illustrates the transformation of primary materials into end products, providing a conceptual visual representation of the processes, machinery, labour, and major environmental discharges involved. They should offer an abstract visual depiction that accurately describes industrial practices and is understandable to both practitioners and academics with the necessary literary background, without requiring further elucidation.

The flowchart can take various forms to represent actual practices most effectively, with Figure 4.13 providing an exemplary flowchart template. Chapter 5 presents a series of flowcharts that illustrate the process of cotton clothing production from seeds to garments.

Figure 4.13 Input-output Production Flowchart Template



Source: The Author

Tool 2: Production Input-Output Tables

PIOTs serves framework for collecting and maintain PIO inputs and outputs data, which can be either structured or flexible depending on the methods and constraints under which the data is collected. Table 4.1 present a production input-output table template.

Table 4.1: Production Input-output Table Template

Table 3.2 Production Input-Output Table_Template										
					Version:	V1	Date:		10/08/2024	
Description				Item	Quantity		$Value/Cost (AU)		Key Contri Process	Data Type (r,a,e,c,s)* /Formula
					Number	Measure	Number	Measure		
			Code	G	H	I	J	K		
Business	Production Capacity		(7)							
Input	Land									
		Land	(9)							
		Water	(10)							
		Electricity	(11)							
		Fossil Fuels	(12)							
		Gas	(13)							
	Material									
		Primary Material	(15)							
		Auxiliary Material	(16)							
	Machinery									
		Primary Machinery (Processing Material)	(18)							
		Parts/Components	(19)							
	Labour									
		Primary Skilled Labour	(21)							
		Supporting Labour	(22)							
		Overheads (incl. Management)	(23)							
	Entrepreneuship									
Output	Economic									
		Annual Output	(26)							
		By-product	(27)							
	Environmental									
		Gegeral Solid Waste	(29)							
		Hazardous Solid Waste	(30)							
		Waste Water	(31)							
		Air Pollutant	(32)							
	Social									
Note	r/reference, a/assumption, e/estimated, c/calculated, s/sample data as example; NS/not significant; LM/too limited to count; NA/not available									

Source: The Author

Tool 3: Production Economic Measures Table

PEcMT consists of selectively structured data records that facilitate financial performance analysis to foster improvements such as increased resource efficiency, waste reduction, and decreased chemical usage, which can inadvertently boost profitability and motivate companies to embrace sustainable practices. For instance, once individual entities recognize the benefits that the industry's best practices can offer, they are likely to assess their own resource utilization and pinpoint areas ripe for enhancement, a natural reaction in the business world as observed. Table 4.2 presents the economic measures developed to date. As highlighted earlier, these measures should be refined in accordance with ongoing business engagement.

Table 4.2: Production Economic Measures Table

Table 3.3 Production Economic Measures Template								
			Version:	V1	Date		10/08/2024	
Category/Production Phases		Remarks	Process #1		Process #2		Process #N	
			Number	Measure	Number	Measure	Number	Measure
	Code							
No. of Business	(7)							
Direct Produciton Labour	(8)							
Over Heads & Contractor	(9)							
Total Labour	(10)							
Primary Product	(11)							
Ttl Production Volumn	(12)							
	(13)							
Production Value	(14)							
Unit Product Value	(15)							
(Average)	(16)							
Best Practice Productivity	(17)							
Average Productivity	(18)							
Comparison **Horizontal - Production Phases**								
Primary Material Input	(21)							
Volumn	(22)							
Cost	(23)							
Labour Cost	(24)							
Gross Profit	(25)							
Primary Material Cost Ratio	(26)							
Average Production Value/Labour	(27)							
Vertical - World								
Best Practice Productivity	(29)							
Average Practice Productivity	(30)							
High End Unit Product Price	(31)							
Average Unit Product Price	(32)							
Note:								

Source: The Author

Tool 4: Production Environmental Measures Table

PEnMT compiles concrete PIO inputs and outputs into three categories: natural resources, chemicals, and wastes, which align with the objectives for analysing this data: efficient utilization of natural resources (SPG I), responsible management of chemicals (SPG II), and the prudent management and reduction of waste generation (SPG III). Table 4.3 displays the environmental measures developed thus far. As previously emphasized, these measures should be enhanced in line with ongoing business engagement.

Table 4.3: Production Environmental Measures

Table 3.4 Production Envioronmental Measures Template										
						Version:	V1	Date	10/08/2024	
Category				Remarks	Process #1		Process #2		Process #N	
					Number	Measure	Number	Measure	Number	Measure
Sustainable Development Goal (UN SDG12 Alignment)		Item	Code	G	H	I	J	K	L	M
SPG I	Efficient Use of Natural Resources	Land	(7)							
		Water	(8)							
		Electricity	(9)							
		Fossil Fuels	(10)							
		Gas	(11)							
SPG II	Responsible Management of Chemicals	Chemical 1	(12)							
		Chemical 2	(13)							
		Chemical 3	(14)							
		Chemical 4	(15)							
		Chemical 5	(16)							
		Other	(17)							
SPG III	Responsible Managing and Reducing Waste Generation	**Waste Water**								
		Total Volumn	(19)							
		COD	(20)							
		BOD	(21)							
		NH3-N	(22)							
		TN	(23)							
		TP	(24)							
		Air Pollutant								
		Total Volumn	(26)							
		PM	(27)							
		Cox	(28)							
		SOx	(29)							
		Nox	(30)							
		TVOC	(31)							
		Solid Waste								
		Cotton Solid Waste	(33)							
		Other Solid Waste	(34)							
		Hazardous Waste	(35)							

Source: The Author

Tool 5: Production Social Measures

The social challenges present within the garment industry encompass child labour, substandard working conditions, wages below a living wage, and excessive overtime, among others. The author personally observed poor working environments, hazardous workspaces, and a lack of protection against air and noise pollution, to name a few. Nevertheless, the author perceives these issues as national or even humanitarian concerns, rather than being uniquely attributable to the clothing industry. Without firsthand data on this subject, the author is currently unable to devise the Production Social Measures. This framework may evolve in subsequent phases, particularly when the author undertakes an extensive array of case studies and gains a comprehensive understanding of these matters during a proposed PhD stage of this research.

Tool 6: Entrepreneurship Measures

Entrepreneurship exerts a decisive impact on the production process and influences various outputs, including economic, environmental, and social dimensions. The methods and measurements that are part of the 5Ms (Manpower, Machinery, Materials, Methods, and Measurements) fall within the entrepreneurial domain as intangible yet essential components of the methodology's input category, which are as significant for successful production as the tangible factors such as labour, materials, and machinery. Entrepreneurship, being a broad and intricate field, demands a substantial investment of time to gather firsthand data through an array of case studies, which is crucial for gaining a comprehensive grasp of the issues targeted by this methodology. Given the current time constraints, the author plans to pursue these investigative endeavours during her intended PhD project.

4.4 Data Collection Methods

As previously explained, the most valuable data encompasses not only a detailed understanding of clothing manufacturing processes but also the accumulated insights and critical thinking approaches related to production problem-solving. This hands-on expertise is the outcome of decades of committed work within the industry, crucial for the advancement of IOPAM and the current success of PIODF to facilitate ongoing data collection initiatives. The IOPAM does not impose strict limitations on data collection techniques; instead, it advocates for flexibility and innovation to align with research goals, with the only constraint being adherence to ethical standards during data gathering. Consequently, data collection techniques should be customized to specific objectives that consider practical limitations through a results-driven problem-solving approach, irrespective of whether they involve quantitative or qualitative strategies such as case studies, surveys, interviews, and so forth. For instance, the achievement of PIODF contributes to iterative processes that begins with a conceptual idea regarding production components and subsequently integrates a comprehensive analysis of the cotton garment manufacturing process, which spans from seeds to the final product (discussed in Chapter 5), along with a theoretical assessment of cotton shirt production aimed at evaluating the global production impact of Australian cotton (investigated in Chapter 6). This utilizes innovative data gathering and production analysis techniques as detailed in the following section 4.6.2.

4.5 Production Analysis Methods

Various methods are available for analysing production data collected through methodological tools based on data saturation. These methods can be applied to individual entities, industry sectors, or entire industries. Each tool offers a unique analytical direction, as detailed below:

The Production Input-Output Flowchart can be established either for an entity or an industry, and the analysis methods can be descriptive or comparative. For instance, Chapter 5 presents a series of input-output flowcharts for cotton clothing production that trace the process from seeds to garments. These flowcharts are crafted based on general practices in Australia (cotton farming and ginning) and China (cotton yarn, fabric production, fabric dyeing, printing, finishing, and garment production), illustrating the production practices within these sectors and countries. Additionally, these flowcharts can serve as a reference for comparison, highlighting any differences that might arise when these processes are operated in other countries, such as those in Europe.

The Production Input-Output Table exhibits flexibility in its customization for individual entities. The data gathered for these entities is amenable to analysis using nearly all existing production analysis techniques, including process mapping, time studies, capacity analysis, cost analysis, quality control, productivity measurement, workflow analysis, efficiency analysis, among others. Furthermore, the aggregation of data from individual entities allows for the estimation of broader sectoral trends and facilitates comparative analyses, benchmarking, and averaging. Through these comprehensive efforts, the data can ultimately contribute to assessing the status of the triple bottom line sustainability and identify strategies for its improvement.

The Production Economic Measures are designed to target the profit maximization of individual entities under investigation, employing data derived from Production Input-Output tables as necessary for rigorous analysis. Comparative analysis enables these entities to position themselves within the industry by comparing against industry benchmarking, standards and averages, whilst also tracking their own developmental progress. Theoretically, the profit-driven nature of the businesses incentivizes them to discern their performance and identify areas for growth. Concurrently, the Production Economic Measures provide a structure that promotes cost analysis and streamlines business reporting processes, facilitating strategic decision-making that is aligned with the goal of enhancing profitability.

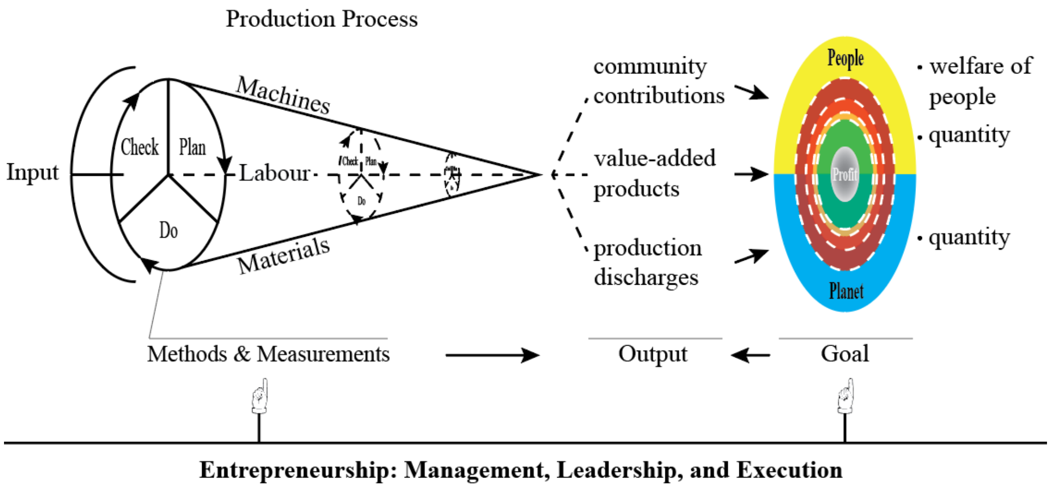
The Production Environmental Measures mirror the functions of their economic counterparts, focusing on the environmental dimensions of production. These measures quantify environmental impacts, offering clear targets and numerical objectives for mitigation efforts. Through comparative and cost analyses, businesses can devise practical action plans that support strategic decision-making aimed at minimizing environmental footprints.

4.6 Methodology Development Progress and Validity Check

4.6.1 The Emergence of Production Input-Output Model

Developing IOPAM involves deep reflection on production management, leading to the emergence of a conceptual Input-Output Production Model (IOPMd) that captures the empirical insights into factors influencing production management effectiveness, as shown in Figure 4.14. This model, in turn, guides a management strategy cantered on data-driven innovation to foster sustainable practices in the clothing industry.

Figure 4.14: Input-output Production Model

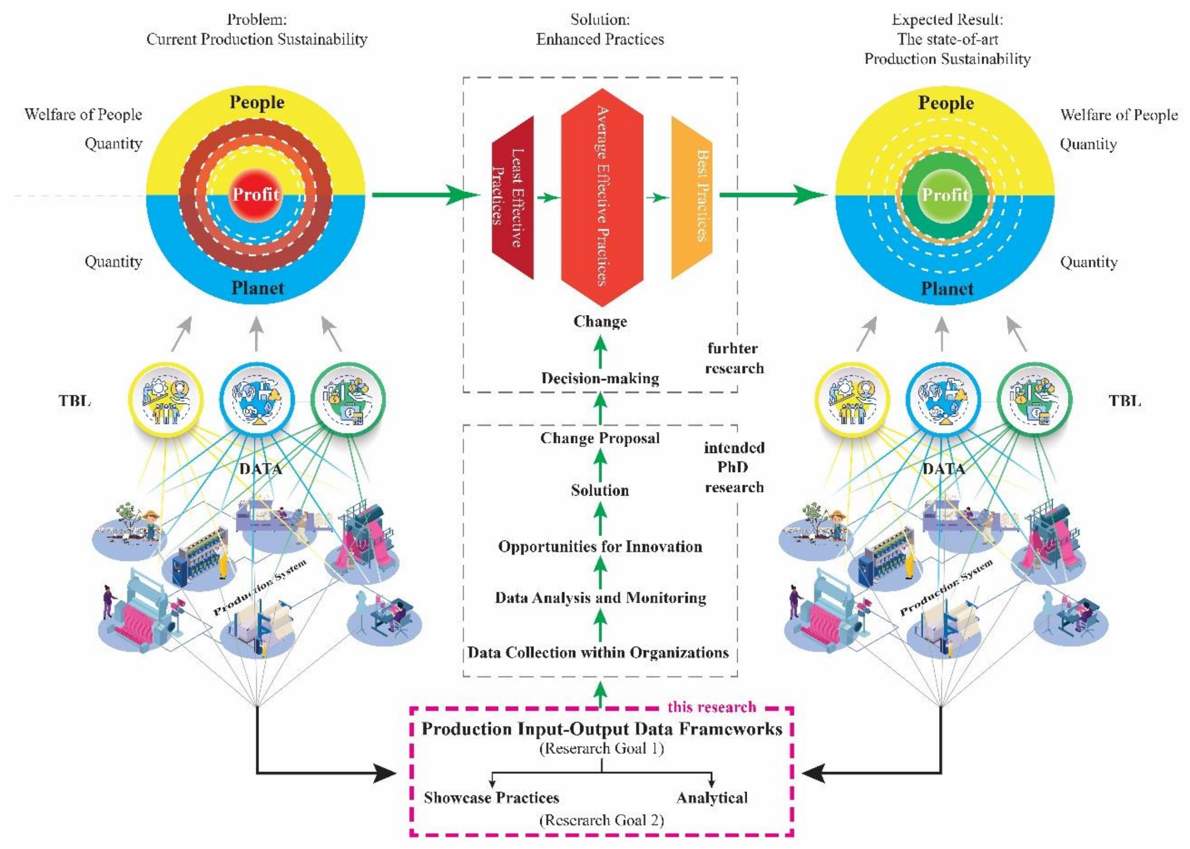


Source: The Author

4.6.2 The Success and Role of PIODF

The PIODF (Objective a) is achieved, which encompasses the IOPMd (Figure 4.15) and the IOPAM Quantitative Components (Figure 4.12). The IOPMd serves as a detailed framework that guarantees the integrity of the data collected and the analyses conducted within this structure, while the IOPAM Quantitative Components, presently tailored for the cotton clothing production sector, are adequate for data collection in this field. As a result, the PIODF establishes a solid foundation for the proposed PhD research and propels initiatives aimed at evolving production sustainability into a cutting-edge standard, as depicted in Figure 4.15. This evolution is anticipated to commence at the organizational level, progressing to the sectoral level, and finally reaching the industrial level.

Figure 4.15: The Role of PIODF



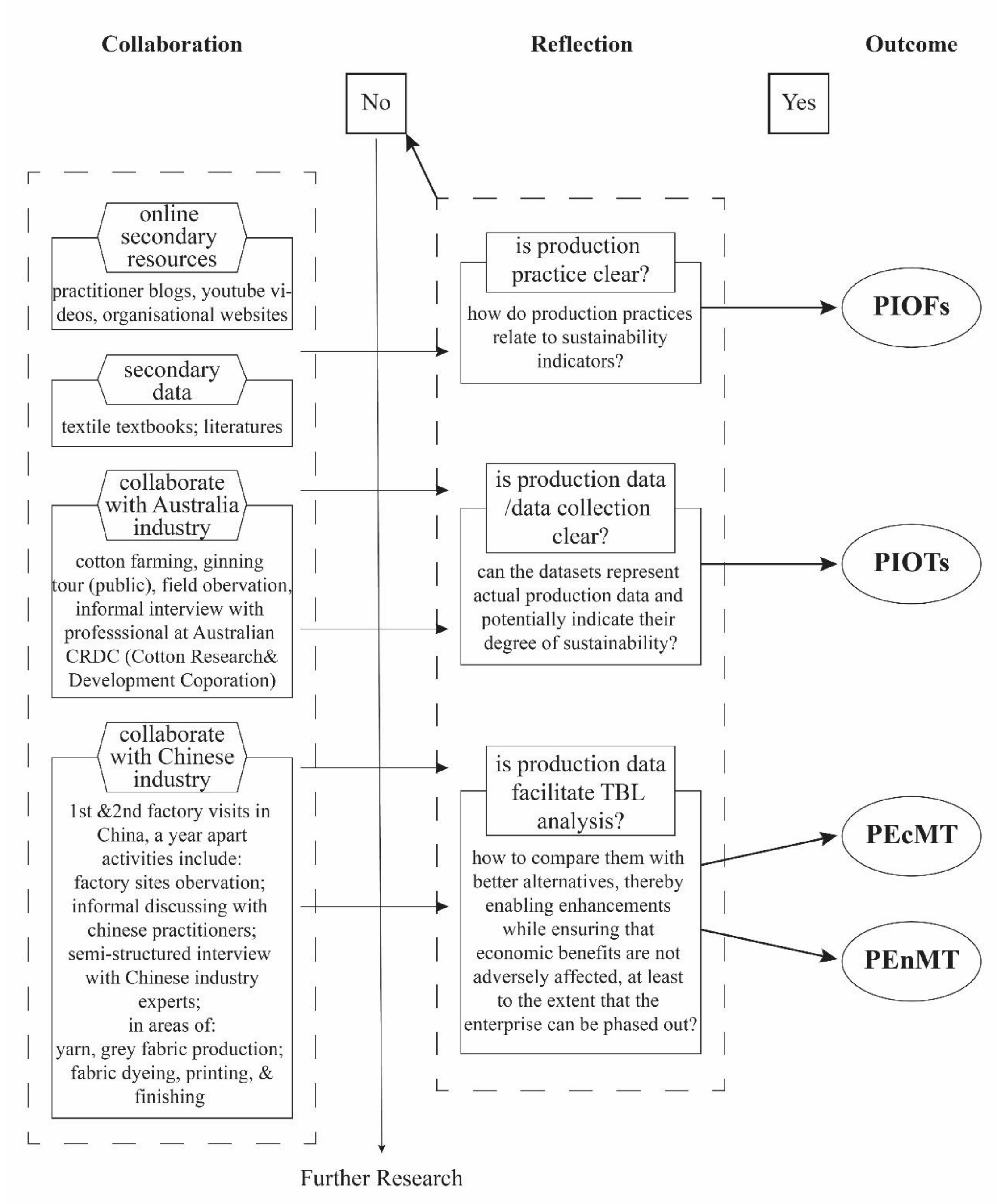
Source: The Author

4.6.3 Data Collection and Production Analysis for PIODF Development

As highlighted, the progression of IOPAM unfolds through iterative cycles of scrutinizing production components, integrating a comprehensive analysis of the cotton garment manufacturing processes within the context of the industry in Chapter 5, along with a conceptual evaluation of cotton shirt production is conducted to assess the global production influence of Australian cotton in Chapter 6, ensuring that the data collection is practical and that the analysis is closely connected to TBL, thereby revealing potential opportunities.

The current data collection and analysis techniques play a crucial role in the success of PIODF, while also enhancing the overall understanding of cotton garment production and revealing economic opportunities for Australia’s clothing sector. The examination of cotton production in Chapter 5 begins with cotton cultivation, followed by cotton ginning in Australia. It then progresses through yarn manufacturing, grey fabric production, and moves on to fabric dyeing, printing, and finishing, ultimately concluding with the final garment production in China due to Australia's limited facilities. The process of data gathering and examination is intertwined and based on or enhances the author's expertise in the industry through iterative cycles, as illustrated in Figure 4.16, involving self-reflection and collaboration with industry professionals and literature for secondary data. The data and analysis for chapters 5 and 6 are conducted using this iterative method. For example, Table 4.4 outlines the data sources used for information collection and flowchart development in each section of Chapter 5, while Table 4.5 provides an example of a web data source. The full list of web data sources is not included because, firstly, the volume and complexity of the sources make compilation challenging, and secondly, much of this data supports the author’s self-reflection process. Furthermore, the data sources relevant to Chapter 6 are presented within that chapter.

Figure 4.16: Data Collection and Analysis for Establishment of PIODF



Source: The Author

Table 4.4: Cotton Clothing Production Phases and Data Source Summary

Produciton Phases /Key Data Summary	Cotton Farming	Cotton Ginning	Yarn Production	Grey Fabric Production	Fabric Dyeing,	Garment Production Cut & Sew	Garment Production Knitwear
Session	5.2.1	5.2.2	5.2.3	5.2.4	5.2.5	5.2.6	5.2.7
Author's Industrial Experience (prior investigation)							
Limited industry	Yes	Yes					
Overseeing tasks			Yes	Yes	Yes		Yes
Hands-on experiences						Yes	
Field Studies (after commencing investigation)							
Field Observation	Yes	Yes	Yes	Yes	Yes	Yes	
Expert Interviews			Yes	Yes	Yes		
Practitioner Insights	Yes	Yes	Yes	Yes	Yes	Yes	
Literature							
"Authoritative website" or "grey data website," such as a practitioner's blog.	Cotton Australia; CRDC; CSD; MyBMP;		Yes	Yes	Yes		
Youtube Educational Video	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Key Publications* (Books)	Cotton Produciton Manual	North Queensland Cotton Gin Assessment and Feasibility Study Report	Spinning Systems and Equipment; Cotton Textile Mill Design (2nd Edition)	Weaving Engineering; Knitting Technology (2nd Edition)	Dyeing and Finishing Process Equipment (3rd Edition); Dyeing and Finishing Process Design	Garment Factory and Production Line Design	
Key publications refer to those that provide direct insights into the formulation of input-output production flowcharts.							

Source: The Author

Table 4.4 Example of Web Data Source

Textile Apex a guide to textile & clothing	https://textileapex.com/ Founder: Abu Sayed, Textile Engineer; Origin: Bangladesh
YouTube	Process of Making Sweater and Knitwear. Korea's Knitting Factory (youtube.com) 製鞋業走向自動化 機械手臂取代人工塗膠 世界翻轉中 20180311 (youtube.com) 【科工力量】"衬衣换波音"，将是对中国纺织业的最大误解 (youtube.com) 運動大牌都是它客戶! 傳統紡織廠變身拚 ESG｜TVBS 新聞 (youtube.com) Traditional Weaving Process in Power Loom (youtube.com)
棉纺织技术	棉纺织技术 (mfzjs.com)
Textile Sustainability Hub	Infographic: Textile and Apparel Industry's Energy and Water Consumption and Pollutions Profile — Textile Sustainability Hub
锦桥®纺织网 www.sinotex.cn 传递纺织信息 搭建贸易桥梁	传递纺织信息，搭建贸易桥梁。(sinotex.cn)

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4.6.4 Further Methodology Advancement

The Input-Output Production Analysis Methodology has been formulated for the examination of clothing production for triple bottom line sustainability. Given that the fundamental principles underlying production are universal across industries, this methodology is, in theory, extendable to encompass various sectors.

As repeatedly highlighted, the methodology is a work in progress and necessitates further refinement. Areas identified for enhancement include, but are not restricted to:

- Development of social measures related to production.
- Formulation of entrepreneurial measures.
- Improvement of all existing measures.
- Enrichment of the methodology by integrating well-established theoretical frameworks such as quality control tools, lean production, Six Sigma, ISO standards(add), etc., following thorough investigation into these concepts.
- Amplification of the methodology through the integration of existing datasets from diverse Life Cycle Inventories after comprehensive analysis.
- Substantial supplementation of the methodology with case studies within the industry, which is crucial given that one of the aims of the methodology is to encourage adoption of practices that foster sustainable production within the industry.
- Enhancement of the methodology by investigating in-depth of the industry decision-making processes.
- Creation of data source management systems.
- Creation of an industrial report template, as an advanced methodology tool, that is concise and formatted for industry reporting, to facilitate the translation of academic findings into actionable insights for industry decision-makers.

Chapter 5 From Cotton Seeds to Garments: Production Process, Inputs, and Outputs

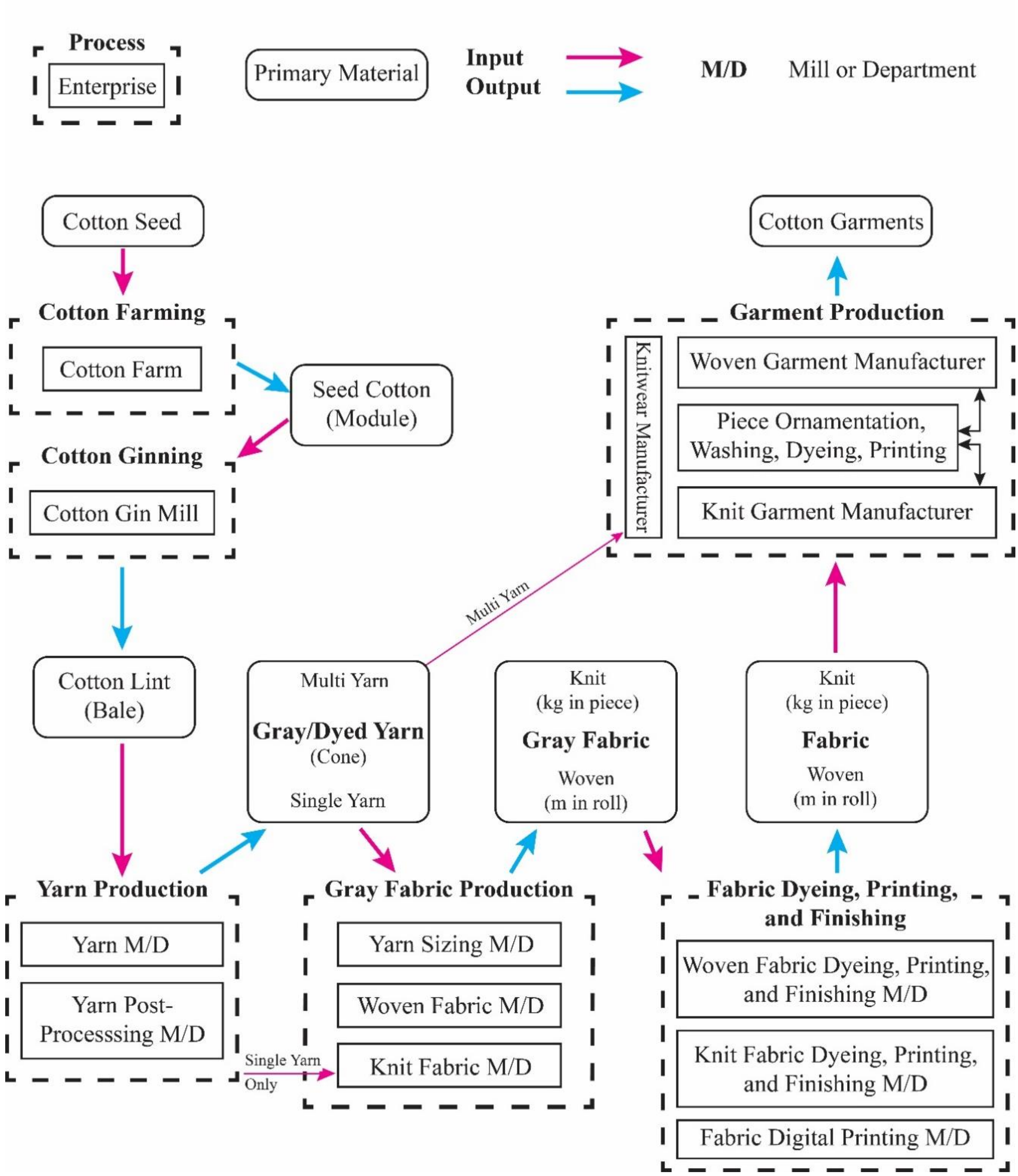
5.1 An Overview

Clothing production is commonly divided into four main stages as outlined in the literature: fibre production, yarn production, fabric production, and garment assembly. This classification is broadly accepted in research and serves its intended purpose. Nevertheless, this study aims to align with industry practices and adopts an input-output perspective that resonates with industrial understanding. Consequently, the clothing production process is further refined into six distinct phases, each demarcated by the primary output, the specific form of cotton material, at each juncture: cotton farming (yielding modules of seed cotton), cotton ginning (resulting in bales of cotton lint), yarn production (producing cotton yarn in cones, hanks, or other less common forms), Grey Fabric production (generating packs of undyed fabric), fabric dyeing, printing, and finishing (creating packs of the final treated fabric), and ultimately garment production (yielding pieces of finished garments), as depicted in Figure 5.1.

During the cotton farming process, cotton seeds are cultivated and nurtured until they grow into cotton bolls. When the cotton bolls reach maturity, whether through natural or controlled means, they are harvested and compacted into modules weighing 2.5 tons by standard. These cotton modules are then transported to ginning factories where the cotton bolls are processed to extract the cotton lint (fibre), which are subsequently packed into bales. In Australia, majority of cotton lint bales, typically weighing 227 kilograms per bale by standard, are exported overseas, primarily to Asia (Department of Primary Industries NSW 2023). Cotton farming and ginning operate in separate entities, functioning independently of each other.

Cotton yarn production involves converting cotton lint from bales into yarn, which is then wound onto cones. Each cone typically weighs between 1.7 to 2 kilograms and is packed in bags or boxes, with options for packing in sets of 12, 24, 36, or customized arrangements. Most of the cotton yarn is subsequently utilized in the fabric production process. However, a portion of it proceeds to the dyeing process to create dyed yarn and wound onto cones, while another portion can be further processed into hand knitting yarn with various packing methods, such as balls, hanks etc. However, in Australia, cotton yarn manufacturing facilities are not commonly found. There are only a limited number of facilities that produce hand knitting cotton yarns from cotton lint after it is cleaned and combed overseas. From the perspective of industry integrity, it may be true that “There are no spinning mills in Australia; all lint is exported” as a report claims. (Cotton Australia and CRDC 2022)

Figure 5.1: Material Flow from Cotton Seeds to Garments



Source: The Author

In the context of literature, "fabric production" refers to the manufacturing process of finished fabrics, typically encompassing two distinct categories of entities: those responsible to produce grey fabric and those dedicated to the dyeing, printing, and finishing stages.

In the case of woven grey fabric production, the process typically involves a yarn doubling factory (optional, for one of the yarn preparation processes), which converts original yarn cones into customized yarn cones. These customized yarn cones are then packed again in bags or boxes and transported to a fabric weaving mill. At fabric weaving mill, yarn is transformed into grey woven fabrics, commonly referred to as "calico" in the industry, through various processes. The "calico" is packaged into rolls or pieces weighing approximately 25kg or customised weight.

The woven Grey Fabric is then transported to the traditional dyeing, printing, and finishing (TDPF) factory and undergo various processes of pretreatment, dyeing or printing or both, depending on the specific requirements. Following this, the fabric goes through the finishing process such as tendering, or more customised finishing process. The final steps in the production include quality control checks and packaging. The fabric is then sold by meters as the unit of measurement and transport to garment manufacturers.

In the case of knitted grey fabric production, the knitting process is generally simpler and faster compared to weaving. The yarn cones are transformed into grey knit fabric through knitting and quality check processes. The resulting fabric is then packed in bags, with each bag weighing approximately 30kg, or as customer requires.

Subsequently, the knit grey fabric is transported to a TDPF factory and undergo all in one pretreatment and dyeing process, and printing process if demanded. Following this, the fabric goes through the finishing process. The final stages of production involve quality control checks and packaging. The fabric is then sold by kilogram as the unit of measurement and transport to garment manufacturers.

Both woven and knit cotton fabric can be digitally printed. The minimum requirement of grey fabric for dyeing is required to be pretreated and go through finishing process at TDPF factory and becomes base fabric (normally in white) for digital printing. The base fabric is then transported to a digital printing factory to transform the bleached base fabric into digital printed fabric.

The garment production process involves the transformation of raw cotton fabrics or, less frequently, yarn into wearable garments. This metamorphosis typically occurs within specialized factories that focus on either woven or knit cut-and-sew garment production, or knitwear garment production, and may also include facilities for garment embellishment, washing, dyeing, and printing at certain garment production stage. The garment production industry is characterized by its complexity, primarily due to a wide range of garment types and styles, diverse trading methods, and significant labour involvement.

This industry encompasses entities of varying sizes, ranging from small one-person businesses to large companies with hundreds of employees, which function as either trading companies or manufacturers. While the garment factory is responsible for carrying out the production processes, the seamless operation of these processes heavily depends on the expertise and collaboration of the garment label owner (brands), and potentially trading entities that may specialize in yarn, fabric, and garments trading, if they are involved.

Those trading entities typically do not own or only own minimal production facilities; they oversee the production process that they are specialized in and serve as the intermediary between the upstream buyer (such as a retailer) and the different entities involved in production.

While the industry is predominantly operated by SMEs, there are also large manufacturing conglomerates with the capacity to handle the entire or a significant portion of the production process in-house, starting from cotton seeds and ending with finished garments. This centralized control results in variations in product quality, profitability, and transparency that reflect the distinct entrepreneurial strategies of these corporations. Despite the variations, the fundamental principles of the production process, along with the inputs and outputs, remain standardized throughout the industry, although they too are differentiated by quality and technology.

The subsequent sessions depict the transformational flow of cotton material through these stages, tracking its evolution from seed to finished product via processes that embody industry norms.

5.2 Visualization of Cotton Seeds to Garments Transformation through Flowcharts

5.2.1 From Cotton Seeds to Seed Cotton: Cotton Farming in Australia

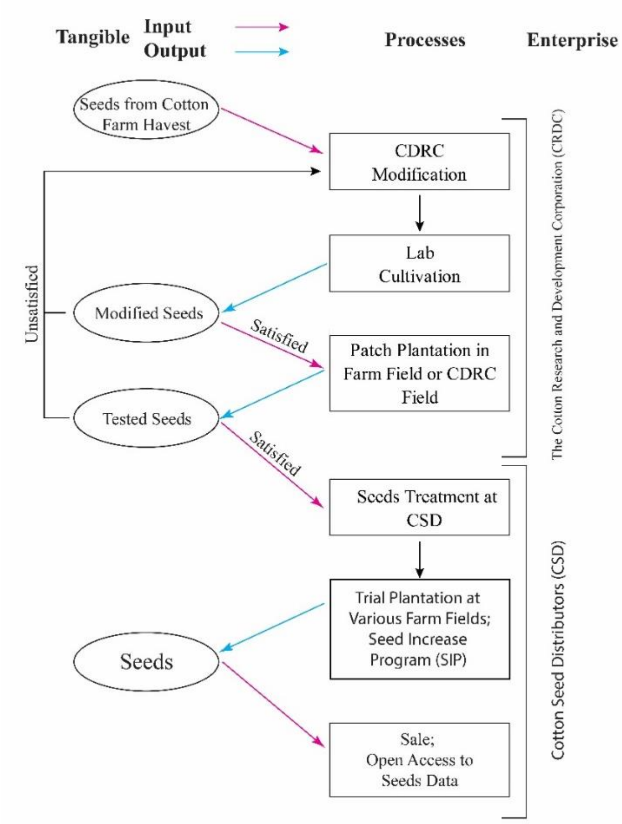
Cotton is predominantly cultivated in China, India, the United States, Brazil, Australia, Pakistan and Turkey, count for around 85% of the world production (USDA Foreign Agricultural Service 2024). While cotton growing may share similarities across countries, variations in the farming process can lead to differing outcomes in terms of yield, quality, and environmental impact. Notably, Australian cotton farming is recognized for its sustainable practices, characterized by premium quality with zero contamination, high yields, and minimal chemical usage (Australian Cotton Shippers Association). Additionally, despite Australia's modest cotton production volume in comparison to China, India, and the USA, its position as the world's third to sixth largest exporter fluctuates seasonally. This suggest that the Australian cotton farming industry is likely a pioneer in achieving triple bottom line success within the global cotton cultivation sector.

The process of Cotton Farming begins with the acquisition of seeds. In Australia, the exclusive supplier of cotton seeds is Cotton Seed Distributors (CSD), which is situated in the Namoi valley in NSW, a significant region for cotton farming. To maintain the high yield and superior quality reputation of Australian Cotton, CSD has worked in partnership with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) since 1971. Cotton Breeding Australia (CBA), a targeted research fund set up to facilitate the research and development of Australian cotton varieties, is the result of the two's partnership since 2007. CBA research activities are supervised by a Management Committee consisting of members from both CSD and CSIRO. Additionally, a Scientific Committee comprising members from CSD, CSIRO, Cotton Research & Development Corporation, and Cotton Australia also provides oversight. The collaboration between these two entities is depicted in Figure 5.2, showcasing their joint efforts in cultivating top-notch cotton seeds.

In summary, the CRDC is responsible for managing the research and testing of cotton seeds, while the Cotton Seed Distributors (CSD) takes charge of distributing the best possible cotton seeds for planting throughout Australia. Collaboration within the Australian cotton industry enables the establishment of a sustainable production model and the achievement of unparalleled global yield rates. As a result, Australian cotton is highly sought after for its exceptional quality, which justifies its premium trading price. Chinese industry practitioners have noted that when the price of cotton of similar grade reaches around US$2,400 per ton, the price of Australian cotton tends to be approximately US$300 per ton higher.

Currently, all cotton seeds in Australia are genetically modified to include insect control traits, utilizing the fifth generation of transgenic insect control seeds. The first generation of commercially released transgenic insect control seeds was introduced in 1996. Typically, it takes around 10 years to develop and introduce a new generation of seeds with enhanced characteristics.

Figure 5.2 Australian Cotton Seeds Cultivation



Source: The Author

In addition to cultivating cotton seeds, CRDC also monitors and improves data related to the entire life cycle of cotton plantations. This data is used to enhance the sustainability of cotton farming practices, which is measured through three pillars: Planet, People, and Paddock. These pilots represent the triple bottom line of the cotton farming industry. Their effort has achieved remarkably. "*Compared to 1992, Australian cotton growers use 97 per cent less pesticides, 52 per cent less water, and 34 per cent less land to grow one bale of cotton.*" (Cotton Research Development Corporation)

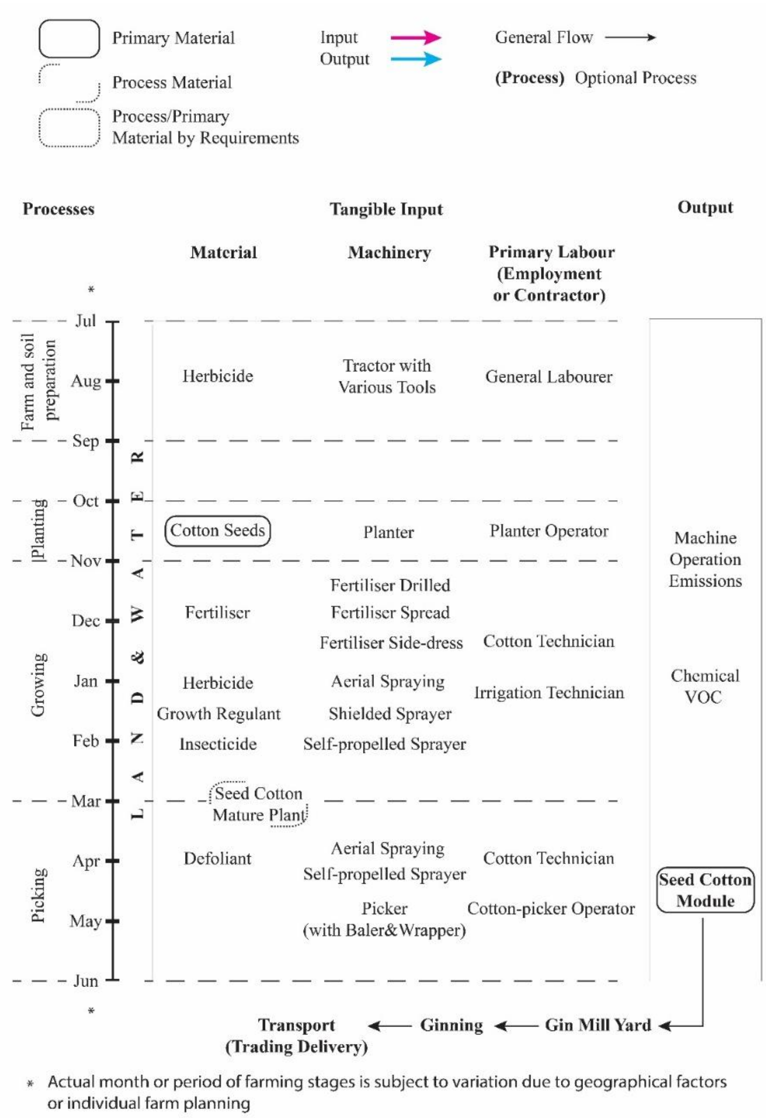
CRDC has the capability to function as a small-scale cotton farm and operate an onsite gin, equipped with all the necessary machinery and materials for cotton farming and ginning. This includes two medium-sized cotton ginning machines suitable for industrial use. Furthermore, they possess a few mini-sized cotton ginning machines that are specifically utilized for preparing seed packs for testing purposes.

The cotton grower acquires seeds from Cotton Seed Distributors (CSD), available in either 20kg or 800kg bags, at an average normal sale price of AU$10 per kg (CSD 2024).

Subsequently, the grower sells the harvested seed cotton, which is packaged in modules weighing 2.5 tons, to either a gin for processing and marketing, or to a marketing intermediary who will locate a gin to process the cotton into lint and cottonseeds (IBISWorld 2024)

Cotton farming typically encompasses several processes, including land and soil preparation, planting, growth, and harvesting, as depicted in Figure 5.3. These processes involve a range of tangible inputs such as materials, machinery, and labour, which contribute to economic outputs (seed cotton module) and environmental outputs (greenhouse gas emissions from machinery operation and pollution of air, soil, and water due to the use of chemicals).

Figure 5.3 Cotton Farming Input-Output Production Flowchart



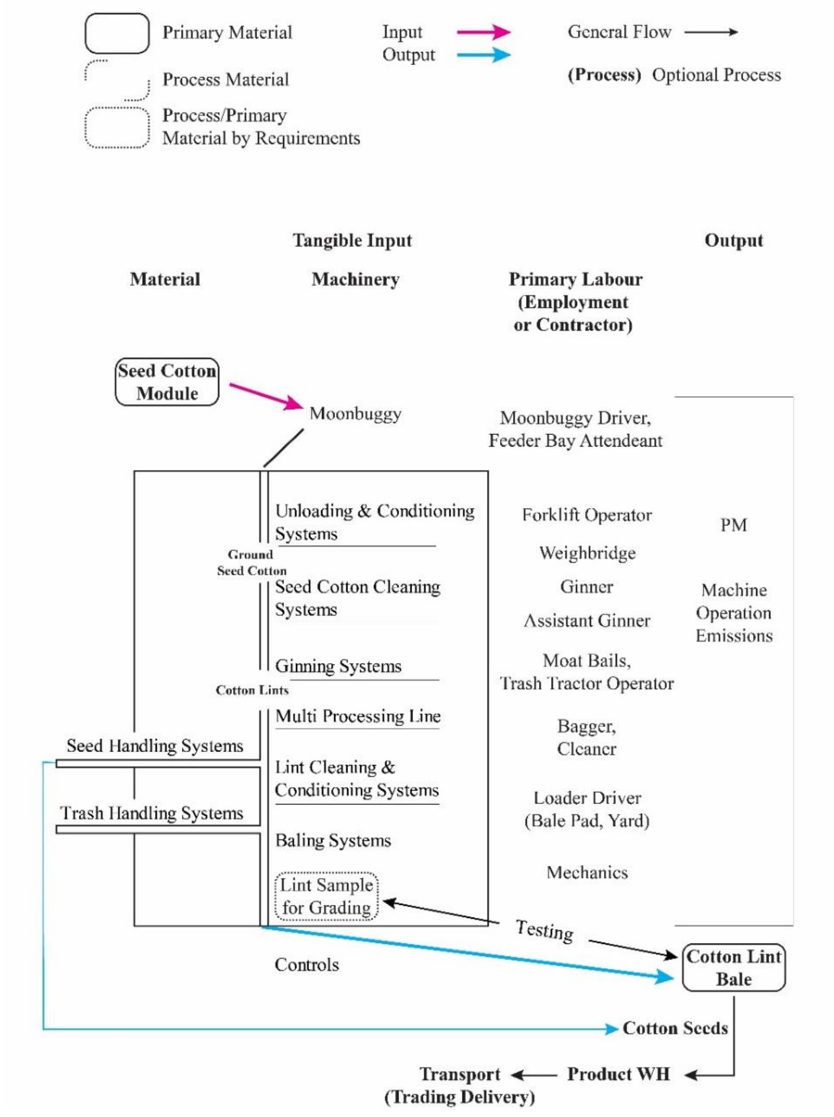
Source: The Author

5.2.2 From Seed Cotton to Cotton Lint: Cotton Ginning in Australia

According to IBIS World, there were 38 cotton ginning businesses operating in Australia in 2021. Cotton ginning businesses has no dominant players in this sector while three major cotton ginning businesses, namely Namio Cotton, LDC Enterprises Australia, and Moreton Pastoral, account for over half of the market share, specifically 24.0%, 18.7%, and 8.7% respectively. (Jeswanth 2022; Trinh 2023).

Cotton ginning is a straightforward process due to the high level of automation in this sector. Figure 5.4 illustrates a cotton ginning input-output flow through this process.

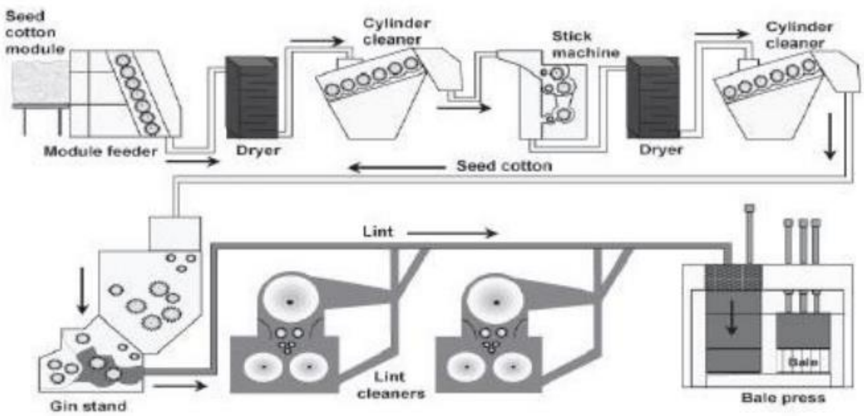
Figure 5.4: Cotton Ginning Input-Output Production Flowchart



Source: The Author

The whole ginning process is complete through a series of machinery, as presented in Figure 5.5

Figure 5.5: Cotton Ginning Production Machinery



Source: North Queensland Cotton Gin Assessment and Feasibility Study Report

5.2.3 From Lint to Yarn: Cotton Yarn Production

Yarn production facilities are categorized based on the type of raw materials they specialize in, focusing on the production of specific materials: cotton yarn, wool yarn, ramie yarn, and silk yarn. The cotton yarn production system, which encompasses a series of machinery and processes, handles cotton fibres and other similar length fibres ranging from 25 to 50 millimetres, such as polyester or cotton/polyester blended staple fibre.

The type of cotton yarn produced is dictated by the needs of its upstream users, predominantly fabric manufacturers. The quality of the yarn is primarily influenced by the quality of cotton fibre supplied by downstream suppliers. As a result, the variety in yarn production is dependent on its intended application and the chosen attributes of the cotton lint, giving purpose to the yarn produced. Typically, yarn diversity is reflected in the manufacturing techniques such as combed or carded, variations in yarn thickness as indicated by the count, and the specific end-use requirements for its upstream utilization. This encompasses applications in weaving for warp or weft, fabric knitting, plying of multiple yarns, light or dark dyeing, bleaching, printing, blending with other materials, and other more specialized uses.

Cotton yarn production is primarily divided into two main systems: carded and combed. The latter essentially consists of a carded yarn production line augmented with additional combing equipment. larger facilities might also incorporate a waste cotton yarn processing system.

Yarn count is an assessment of a yarn's fineness or thickness and plays a crucial role in determining the quality, strength, and utility of yarn for fabrics and other textile applications. The primary methods for quantifying yarn count are divided into direct and indirect systems. The direct system includes measures such as Tex, Decitex, and Denier, while the indirect system includes Ne (English Cotton Count) and Nm (Metric Count). Internationally, Tex serves as the standard, representing the number of grams per 1000 meters of yarn, whereas in China, the English count (Ne, S) is widely used, indicating the number of 840-yard lengths in one pound of yarn. For instance, a 14.5 Tex cotton yarn signifies that one kilometre of yarn weighs 14.5 grams, which can be converted to Ne 40S yarn. An 18/2 Tex cotton yarn indicates that one kilometre of yarn consists of 2 plies and weighs 36 grams (18 grams per ply), which can be converted to Ne 32/2S.

In general, factories concentrate solely on specific types of yarns that fall within their production specialization, which includes optimizing the use of equipment, labour, and material resources. Table 5.1 represent the products range of a yarn manufacturing plants.

Table 5.1: Products Range of a Yarn Manufacturing Plant

Yarn Code (China)	**Material**	**Combed /Carded**	**Yarn Count**		**Use Type**
			Tex	**NE**	
T/JC13tex T	TC (65/35)	Combed	13	45S	Warp Yarn
T/JC13tex W	TC (65/35)	Combed	13	45S	Weft Yarn
20tex T	Cotton	Carded	20	30S	Warp Yarn
20tex W	Cotton	Carded	20	30S	Weft Yarn
26tex T	Cotton	Carded	26	23S	Warp Yarn
28tex W	Cotton	Carded	28	21S	Weft Yarn
R28tex	Cotton	Carded	28	21S	Hank Yarn
T/JC28tex W	TC (65/35)	Combed	28	21S	Weft Yarn
T/JC13tex/2 W	TC (65/35)	Combed	13/2	45S/2	Weft Yarn
T/C: Polyester/Cotton; JC: Combed Cotton; T: Warp Yarn; W: Weft Yarn; R: Hank Yarn					

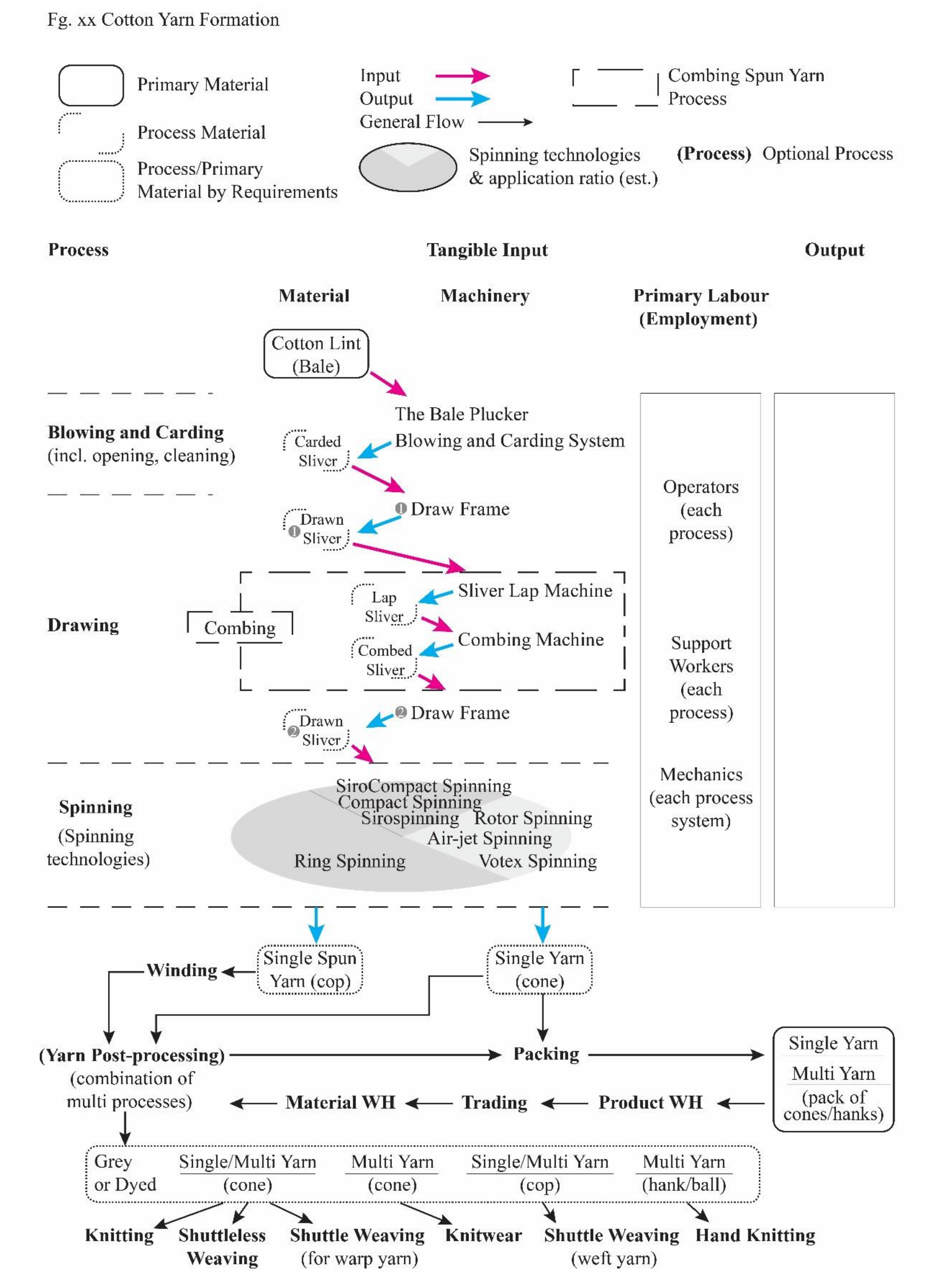
Source: Cotton Textile Mill Design, 1st Edition (Textile Textbook in Chinese)

Figure 5.6-5.12 explains the process of how cotton lint is transformed into yarn through a series of processes. Some processes are essential, while others are optional or alternative. The choice of these additional processes can significantly impact the outcome, particularly regarding the quality of the final product and operational costs, including electricity consumption, which affects profit margins. However, when deciding on these alternative procedures, environmental considerations are rarely taken into account by decision-makers.

The creation of yarn typically encompasses three key stages: preliminary spinning, the spinning process itself, and subsequent post-processing. Figure 5.6 primarily illustrates the preliminary spinning phase, which involves transforming cotton lint into draw slivers that can then be spun into single yarns using various spinning technologies. This stage differentiates between carded yarn and combed yarn by incorporating additional sliver lap and combing machinery into the carded production system. Combed yarn is generally reserved for higher quality end products into the carded production system. The latter is generally for better quality end use.

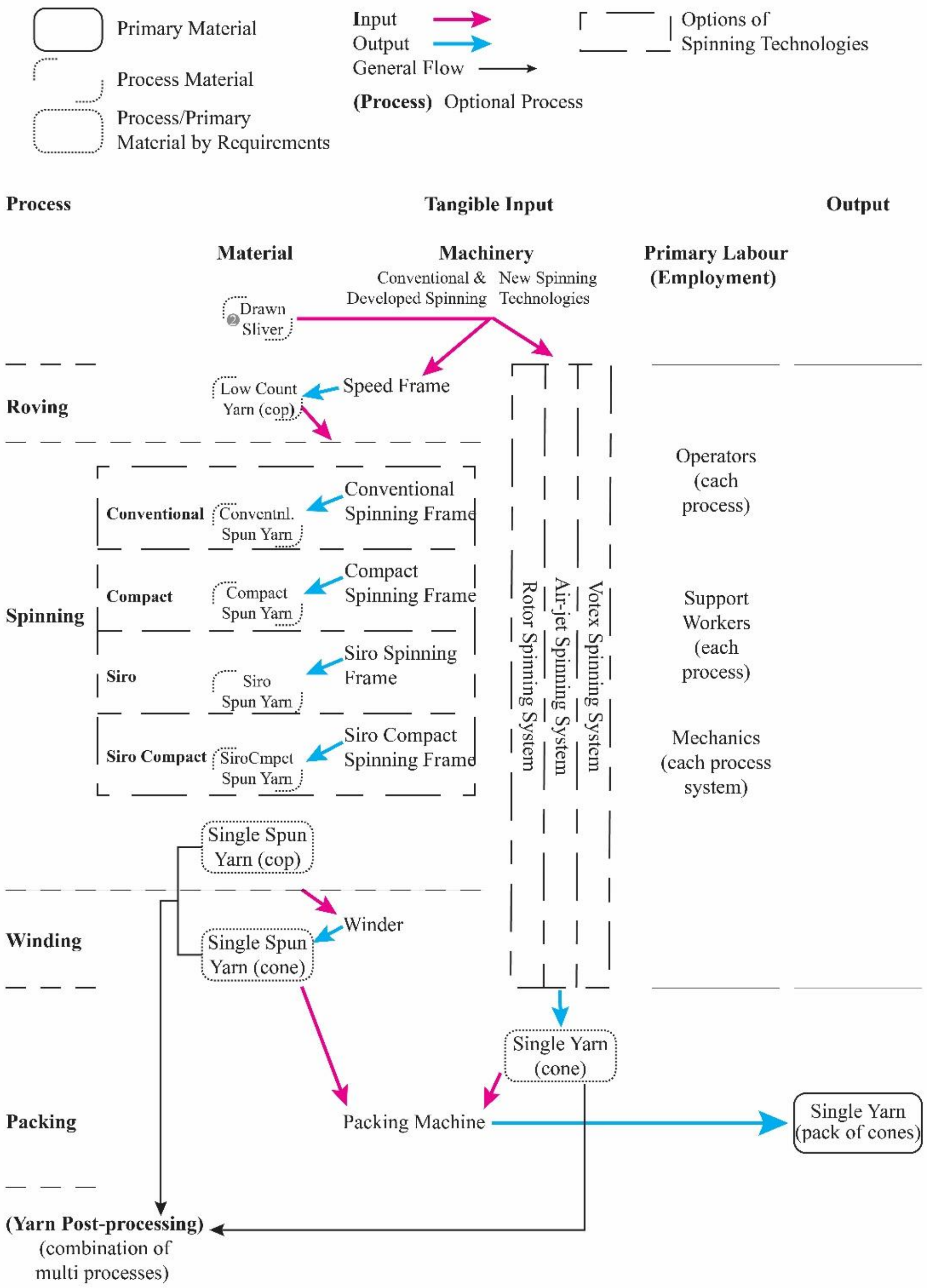
Figure 5.7 showcases the principal spinning technologies employed in the industry, which can be categorized into conventional and innovative open-end spinning methods. Conventional spinning technology yields spun yarn, while open-end spinning technology produces OE yarn. The former often results in finer and higher quality yarn compared to the latter. Some of the finest cotton yarns can only be achieved through conventional spinning technology, especially with advanced techniques such as Siro, compact, and Siro/compact spinning. Nevertheless, open-end spinning offers a direct transformation of drawn sliver into yarn using machinery that consumes significantly less electricity, contributing to its growing popularity.

Figure 5.6: Cotton Yarn Formation



Source: The Author

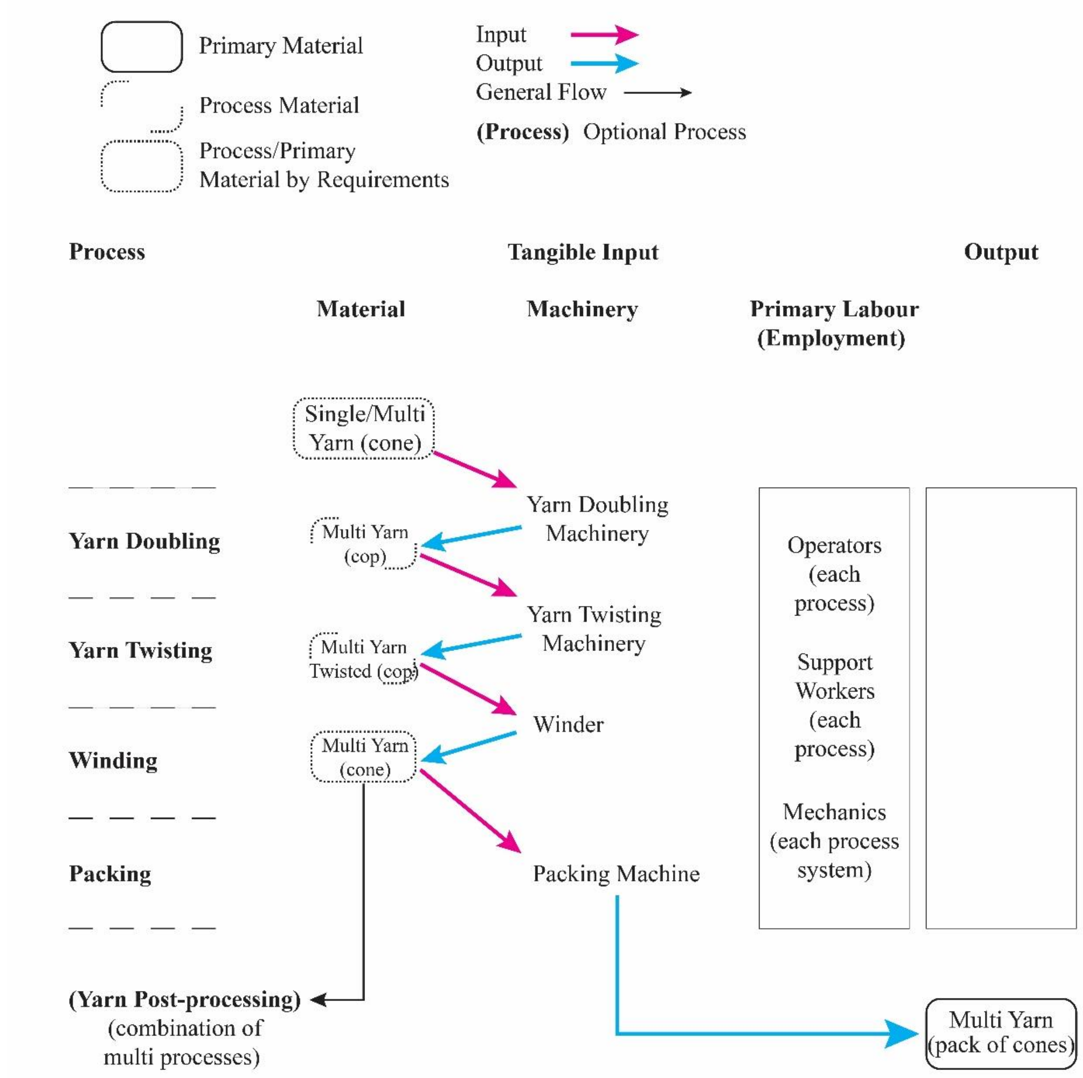
Figure 5.7: Cotton Yarn Spinning Technologies



Source: The Author

Post-processing of yarn is aimed at creating variety in yarn types, enhancing yarn characteristics, or achieving both objectives. Figure 5.8 illustrates the transformation of single yarns into multi-yarns, a crucial step for certain applications. For instance, in knitwear production, where yarn is often formed directly into garments, there's a requirement for yarn with substantially enhanced strength.

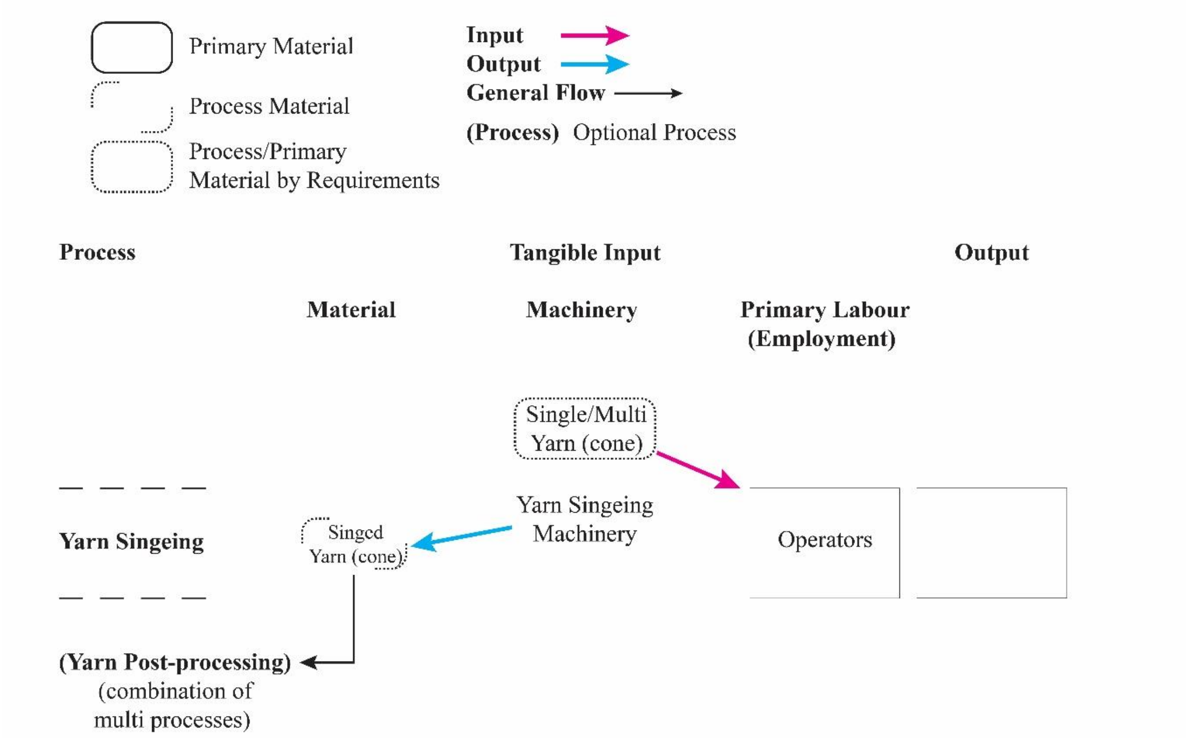
Figure 5.8: Cotton Yarn Post-processing: Doubling and Twisting



Source: The Author

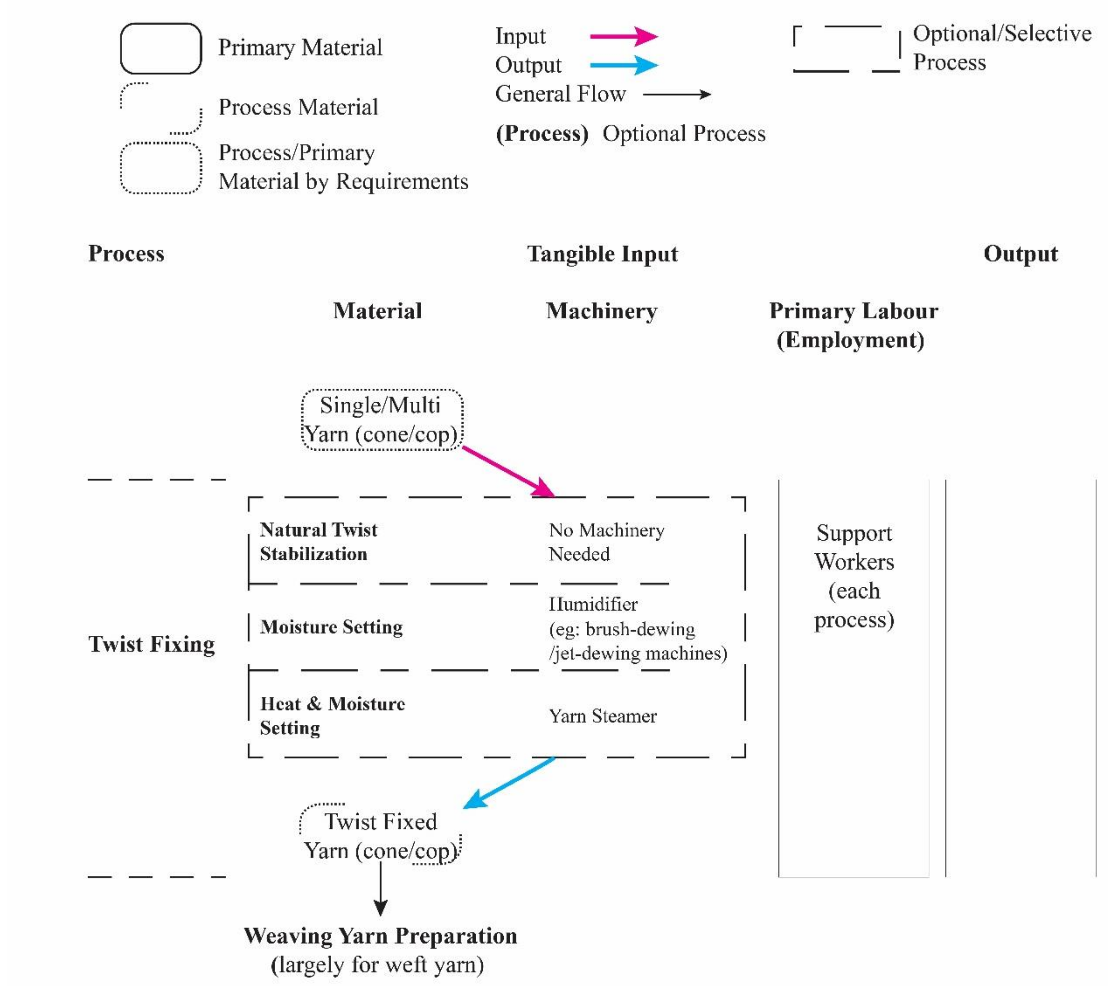
Figure 5.9 demonstrates the singeing process, which renders the yarn smoother and more amenable for weaving or knitting into fabric, as well as preparing it for dyeing, whether at the yarn or fabric stage.

Figure 5.9: Cotton Yarn Post-processing: Yarn Singeing



Source: The Author

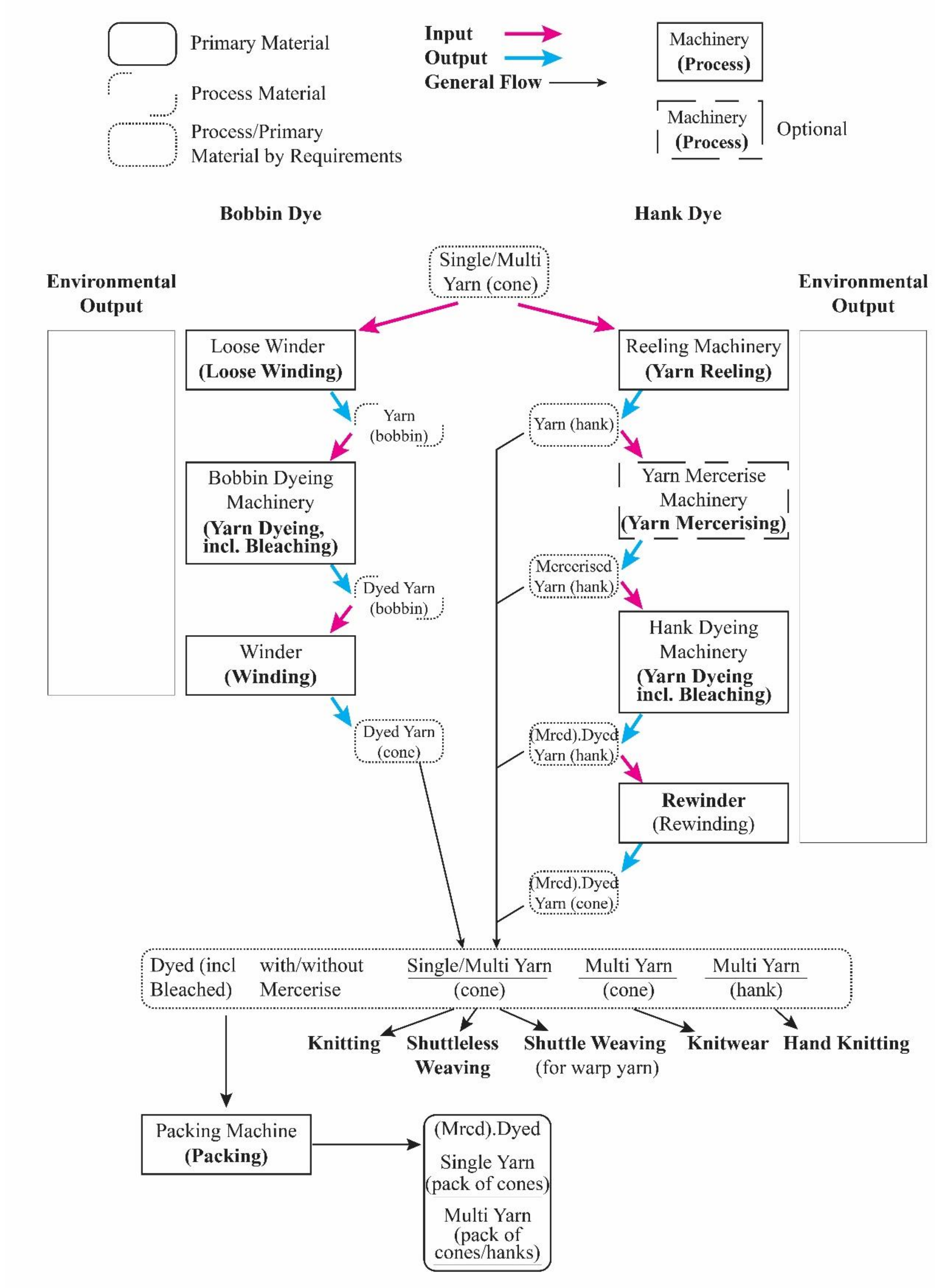
Figure 5.10: Cotton Yarn Post-processing: Twist Fixing



Source: The Author

In addition to fabric dyeing, yarn dyeing is another technique that contributes to creating coloured garments. There are several methods for dyeing yarn, with the most common being bobbin dyeing and hank dyeing, as illustrated in Figure 5.11. Notably, mercerized yarn is usually produced through the hank dyeing process, which involves treating the yarn with a solution of caustic soda. (sodium hydroxide).

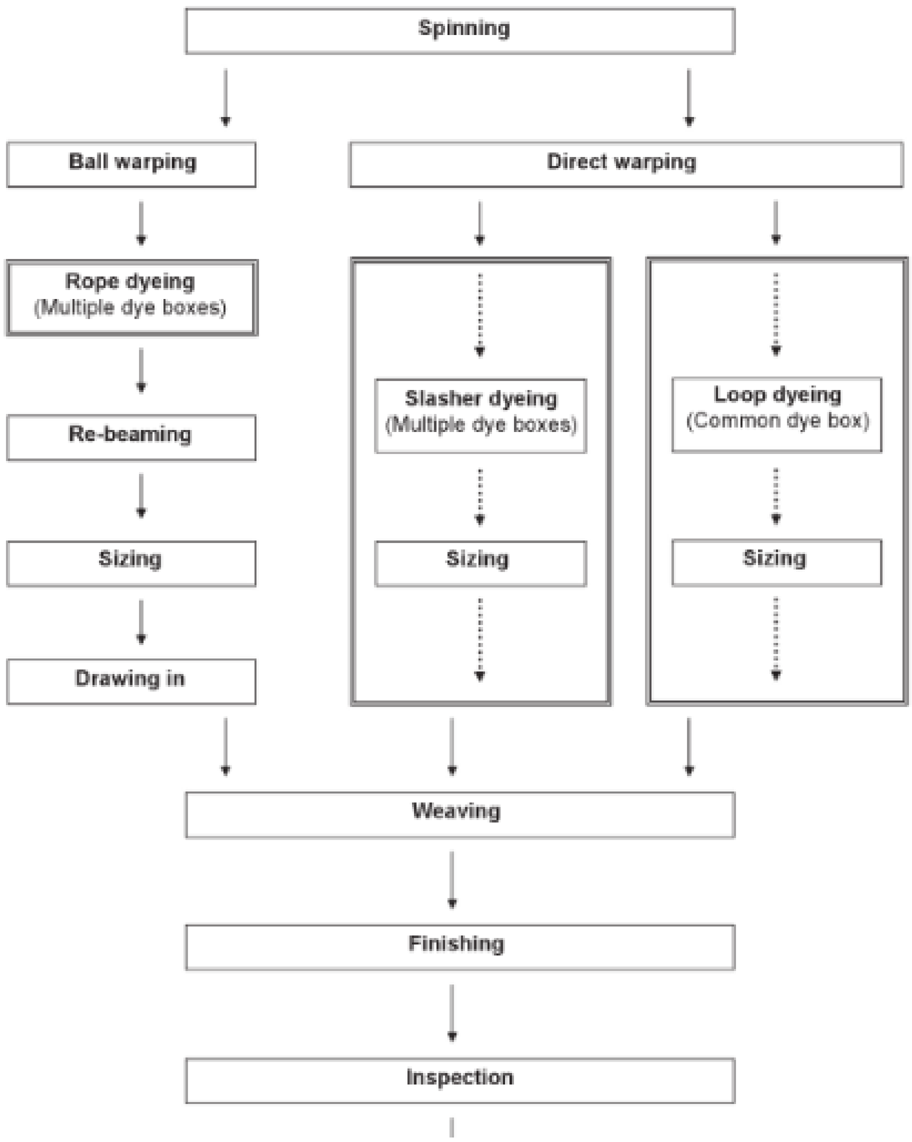
Figure 5.11: Cotton Yarn Post-processing: Yarn Dyeing



Source: The Author

For coloured fabrics, yarn dyeing accounts for a smaller portion compared to fabric dyeing. However, for denim products, yarn dyeing is more common, with rope dyeing, slasher dyeing, and loop dyeing being the predominant methods. Roshan (2015) provides detailed explanations of how these dyeing methods operate, as illustrated in Figure 5.12.

Figure 5.12: Different Yarn Dye Methods



Source: Denim Manufacture, Finishing and Applications (Book)

5.2.4 From Yarn to Grey Fabric: Cotton Fabric Production

There are two primary techniques for producing grey fabrics: weaving and knitting. Yarn intended for weaving is transformed into grey woven fabric through a sequence of machinery and processes specific to the weaving technique. Likewise, yarn destined for knitting is converted into grey knitted fabric using a different set of machinery and processes designed for the knitting technique. Typically, factories are outfitted with either weaving or knitting equipment, specialized for one of these production methods.

Fabric production facilities are categorized based on the type of raw materials they specialize in, focusing on the production of specific materials: cotton and cotton blends staple fabric, wool fabric, ramie fabric, silk fabric, polyester filament fabric, and special fibre fabric. The cotton grey fabric production system, which encompasses a series of machinery and processes, transforms cotton yarn and cotton blends yarn, such as polyester or cotton/polyester blended yarn, to grey fabric.

In general, factories concentrate solely on specific types of fabric that fall within their production specialization, which includes optimizing the use of equipment, labour, and material resources. Table 5.2 illustrates the range of products from a grey fabric production plant as an example.

Table 5.2 A Fabric Factory's Products Range - Example

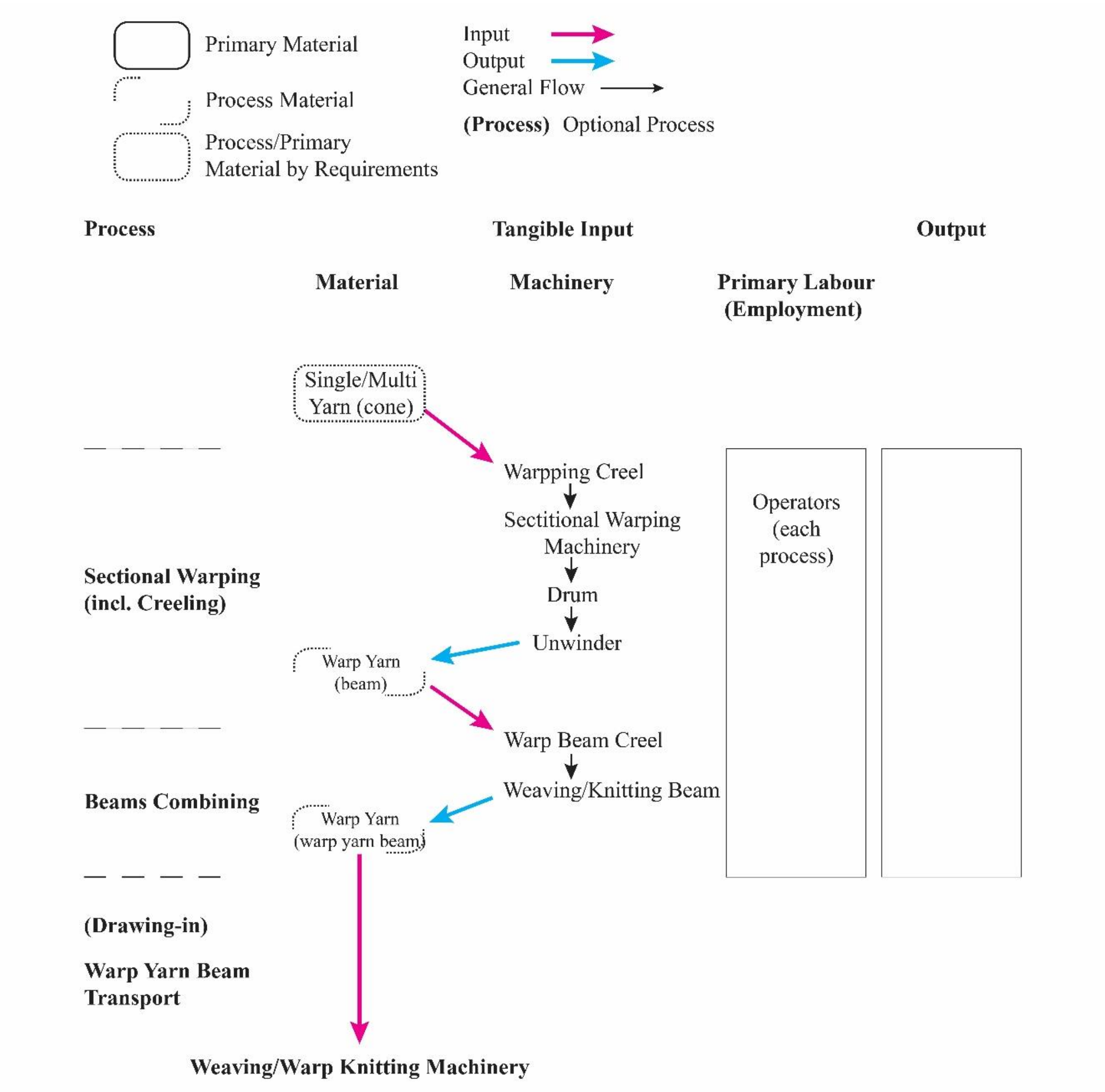
Fabric Name	**Description**
T/JC13/2tex x T/JC28tex Polyester/Cotton Khaki Fabric	Polyester/Cotton Khaki Fabric, Combed, 13/2 x 28 tex
T/JC13tex x T/JC13tex Cotton Poplin Fabric	Polyester/Cotton Poplin Fabric, Combed, 13x13 tex
20x20 tex Cotton Plain Weaving Fabric	Cotton Plain Weaving Fabric, Carded, 20x20 tex
26x28 tex Cotton Plain Weaving Fabric	Cotton Plain Weaving Fabric, Carded, 26x28 tex
T/C: Polyester/Cotton; JC: Combed Cotton; Source: DCY04, Cotton Textile Mill Design (1st Edition)	

Figure 5.13 – 5.20 illustrates the process by which cotton yarn is transformed into fabric through weaving or knitting techniques. Variation of processes can impact the final product's quality and operational costs, such as electricity consumption, which affects profit margins. However, environmental considerations are often overlooked by decision-makers when selecting alternative procedures.

Fabric production generally consists of three main stages: yarn preparation, weaving or knitting, and fabric finishing. Yarn preparation involves getting the warp and weft yarns ready for the next step. For weaving, both warp and weft yarns are needed. In warp knitting, only warp yarn is required, while in weft knitting, only weft yarn is used. Warp yarn preparation is done through warping, which converts multiple yarn cones into a calculated number of yarn beams necessary to produce the desired quantity of fabric. The two primary methods of warping are sectional warping and batch warping.

Figure 5.13 illustrates the sectional warping process for preparing warp yarn used in both weaving and knitting, applicable to various yarn materials. However, cotton warp yarn for weaving generally requires sizing, especially for single fine yarns, to protect the yarn and prevent breakage during the weaving process. This warping method necessitates a separate sizing process for cotton warp yarn.

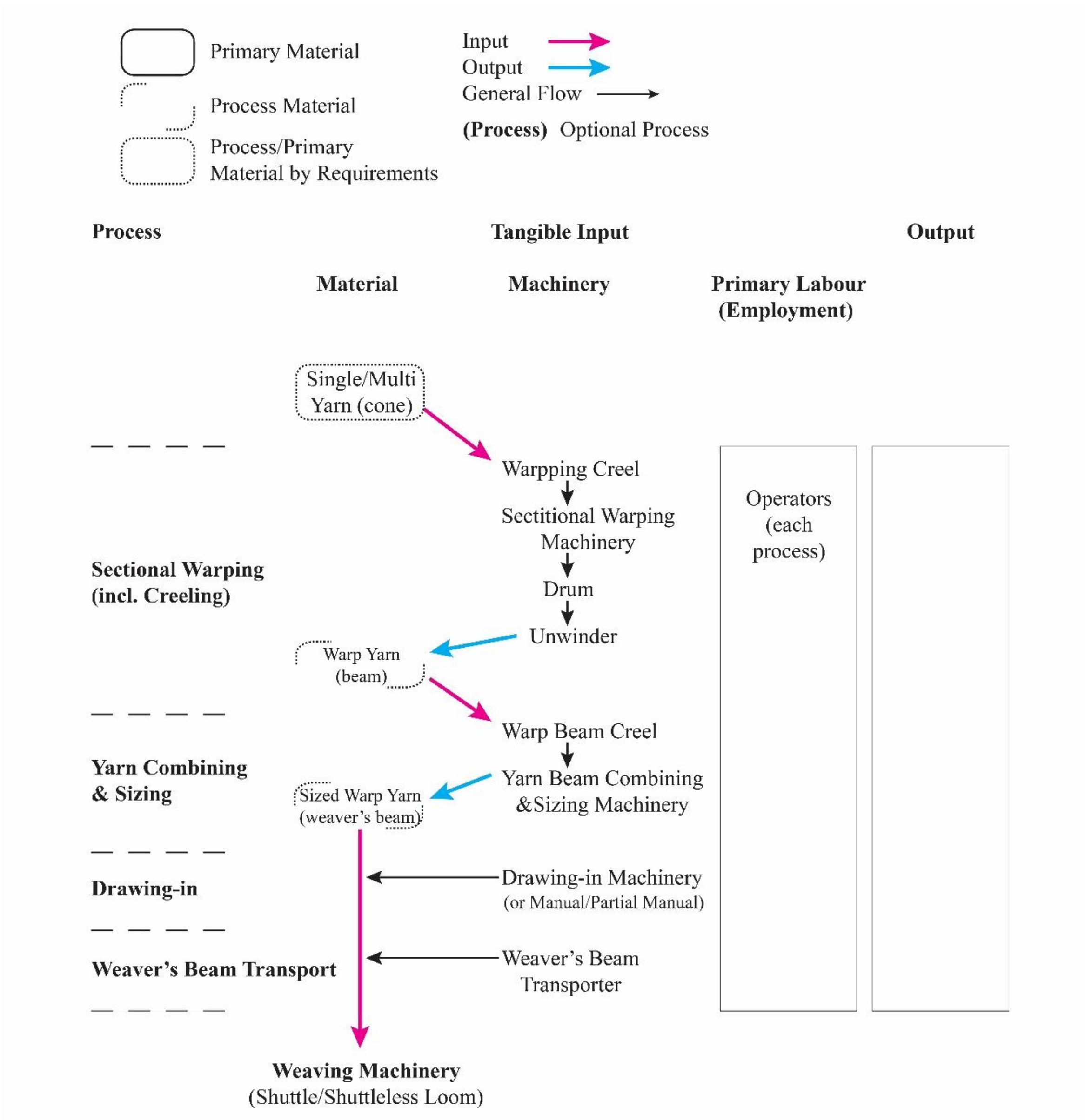
Figure 5.13: Fabric Weaving & Knitting _Warp Yarn Preparation _Sectional Warping



Source: The Author

A method that integrates both sectional warping and sizing processes, as depicted in Figure 5.14, streamlines the transition from yarn cones to weaver's beams and reduces associated costs. This technique is commonly employed for the preparation of cotton warp yarns.

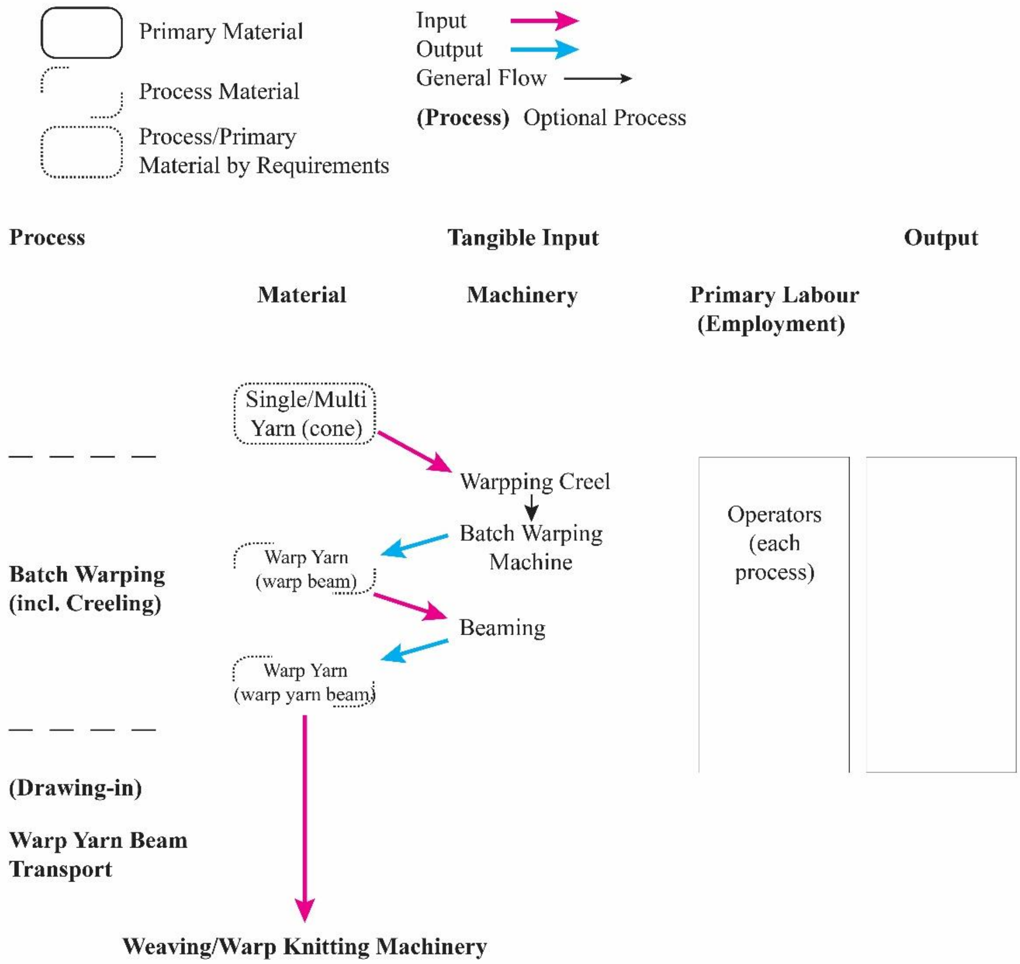
Figure 5.14: Fabric Weaving _Warp Yarn Preparation _Sectional Warping & Sizing



Source: The Author

As depicted in Figure 5.15, batch warping involves the direct winding of yarn onto warp beams in predefined batches, which are then assembled (a process known as beaming) for subsequent use in weaving or warp knitting.

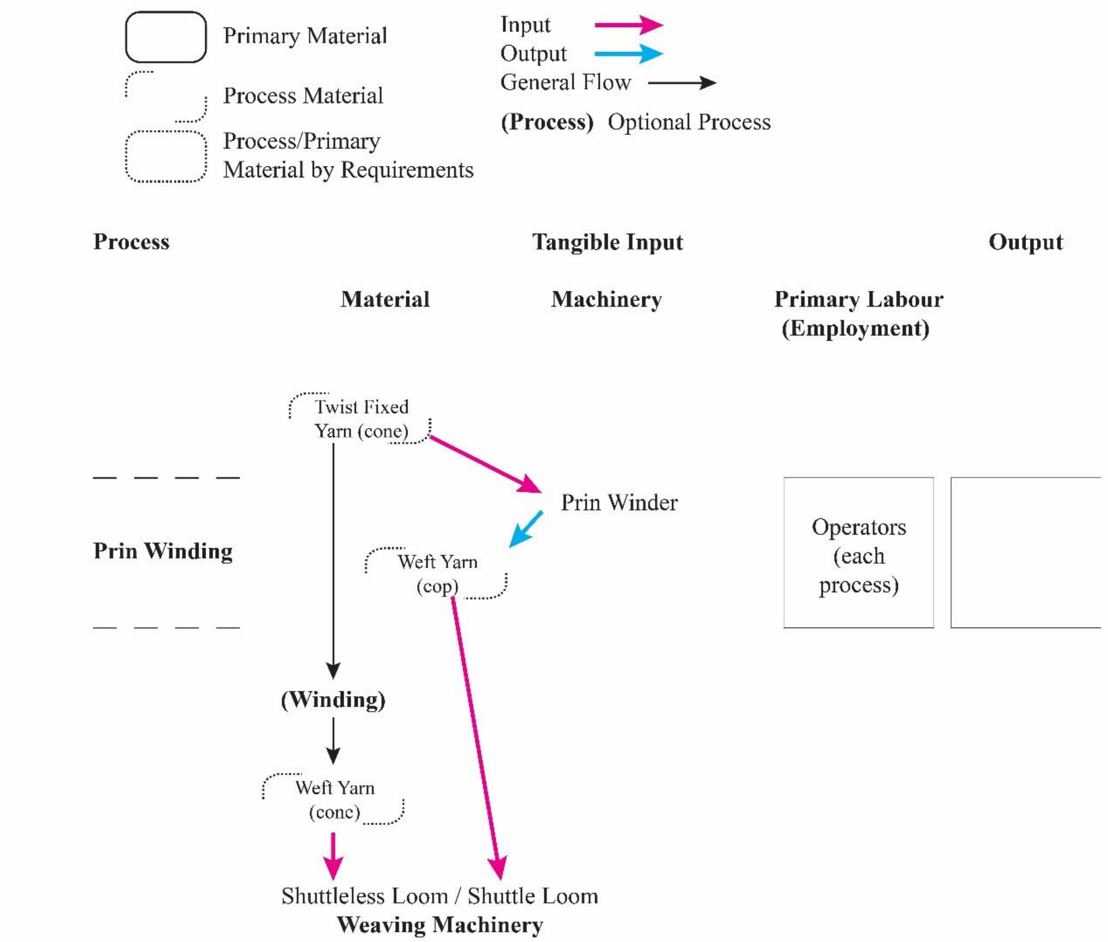
Figure 5.15: Fabric Weaving & Knitting _Warp Yarn Preparation _Batch Warping



Source: The Author

The process of preparing weft yarn is generally uncomplicated, as illustrated in Figure 5.16. Cone yarn can be utilized immediately or rewound for application in shuttleless weaving or weft knitting operations. For traditional shuttle weaving, the weft yarn might be produced directly during the spinning stage and subsequently fed into a shuttle loom. Nevertheless, it is more common to rewind the yarn, a process referred to as pirn winding onto a pirn that is then used to supply the yarn to a shuttleless loom.

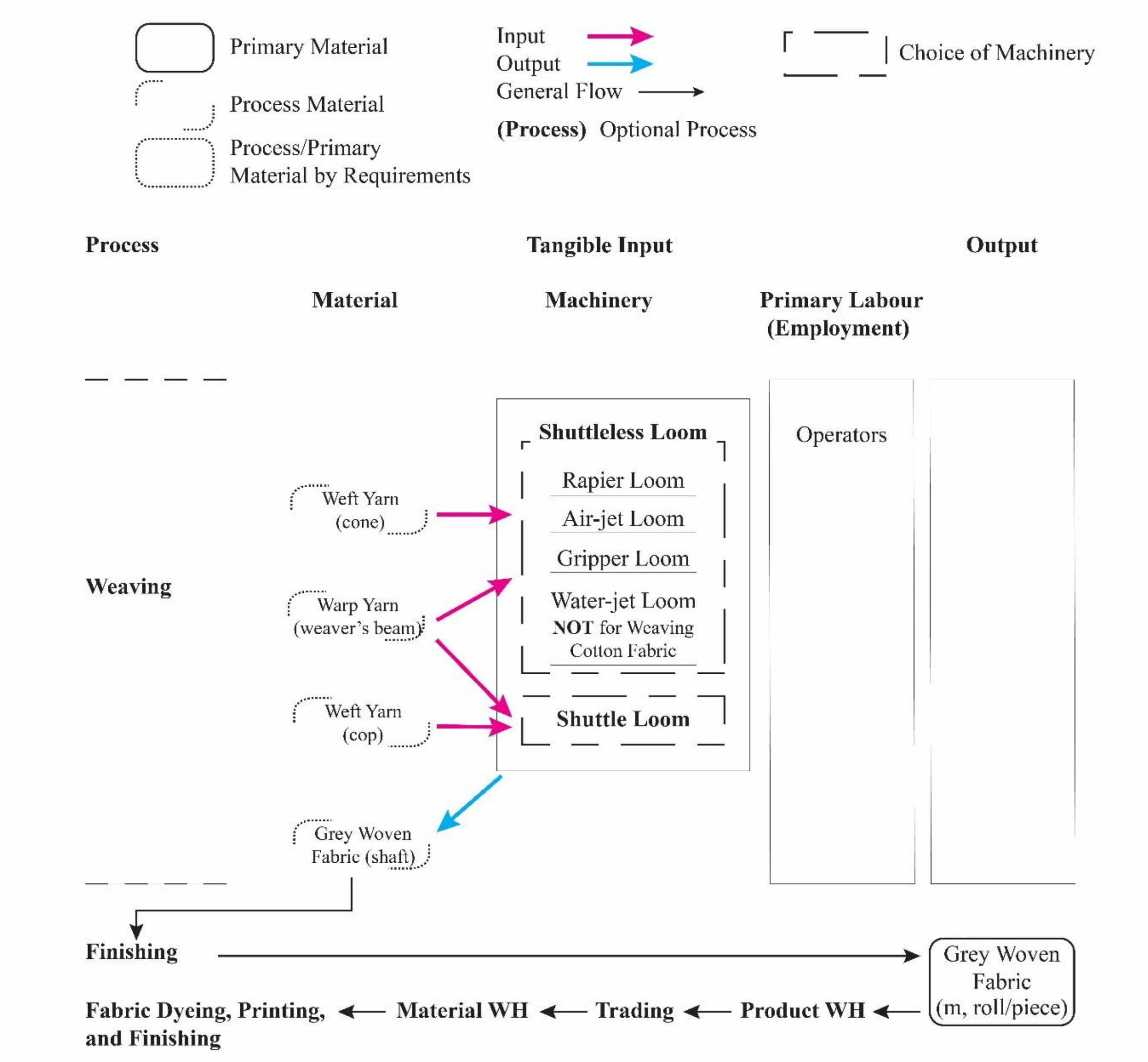
Figure 5.16: Fabric Weaving _Weft Yarn Preparation



Source: The Author

Weaving is a straightforward process that involves feeding the warp yarn and weft yarn into various types of looms to create the base fabric, as illustrated in Figure 5.17. The same underlying principle governs both weft knitting and warp knitting.

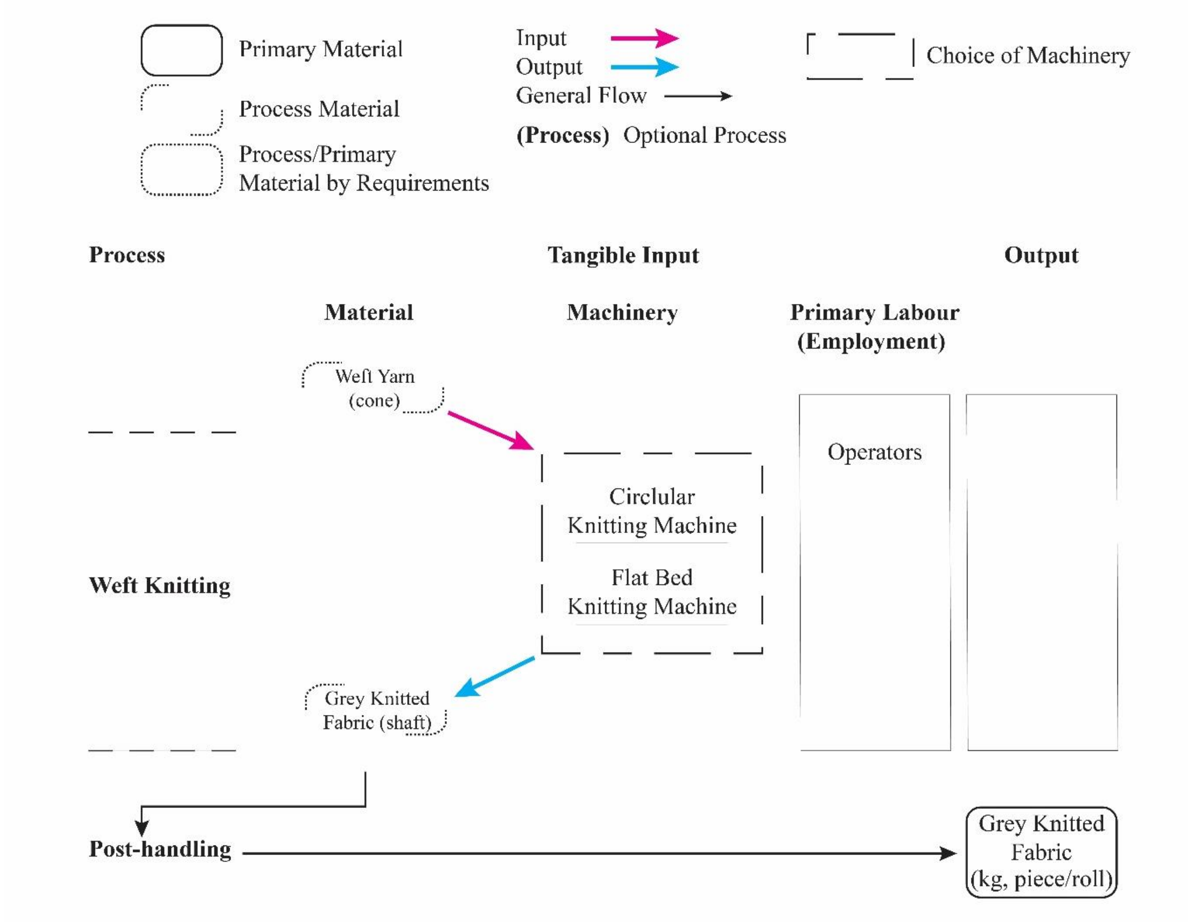
Figure 5.17 Fabric Weaving _Weaving



Source: The Author

Figure 5.18 illustrates weft knitting process

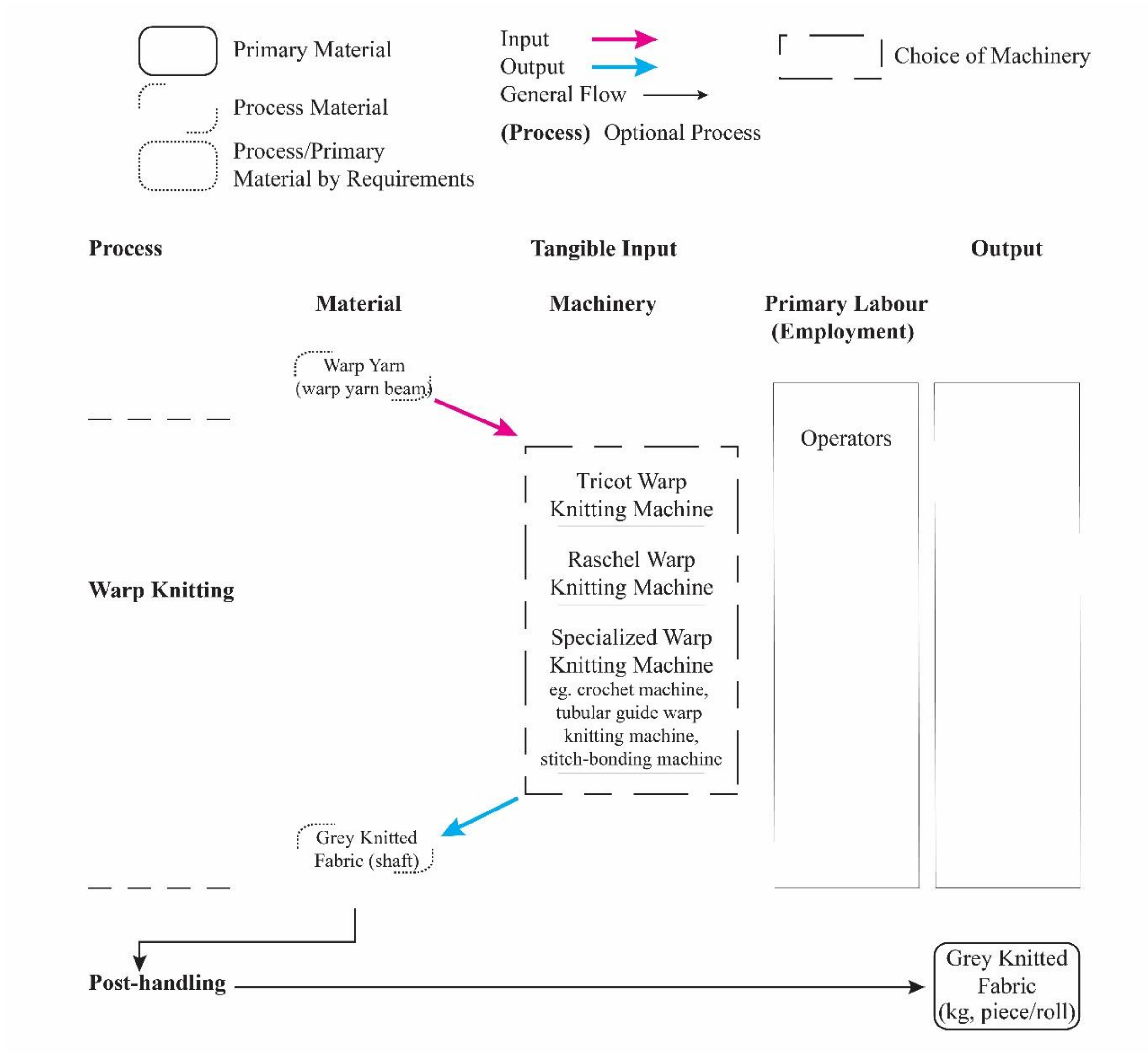
Figure 5.18 Fabric Knitting _Weft Knitting



Source: The Author

Figure 5.19 depict warp knitting process

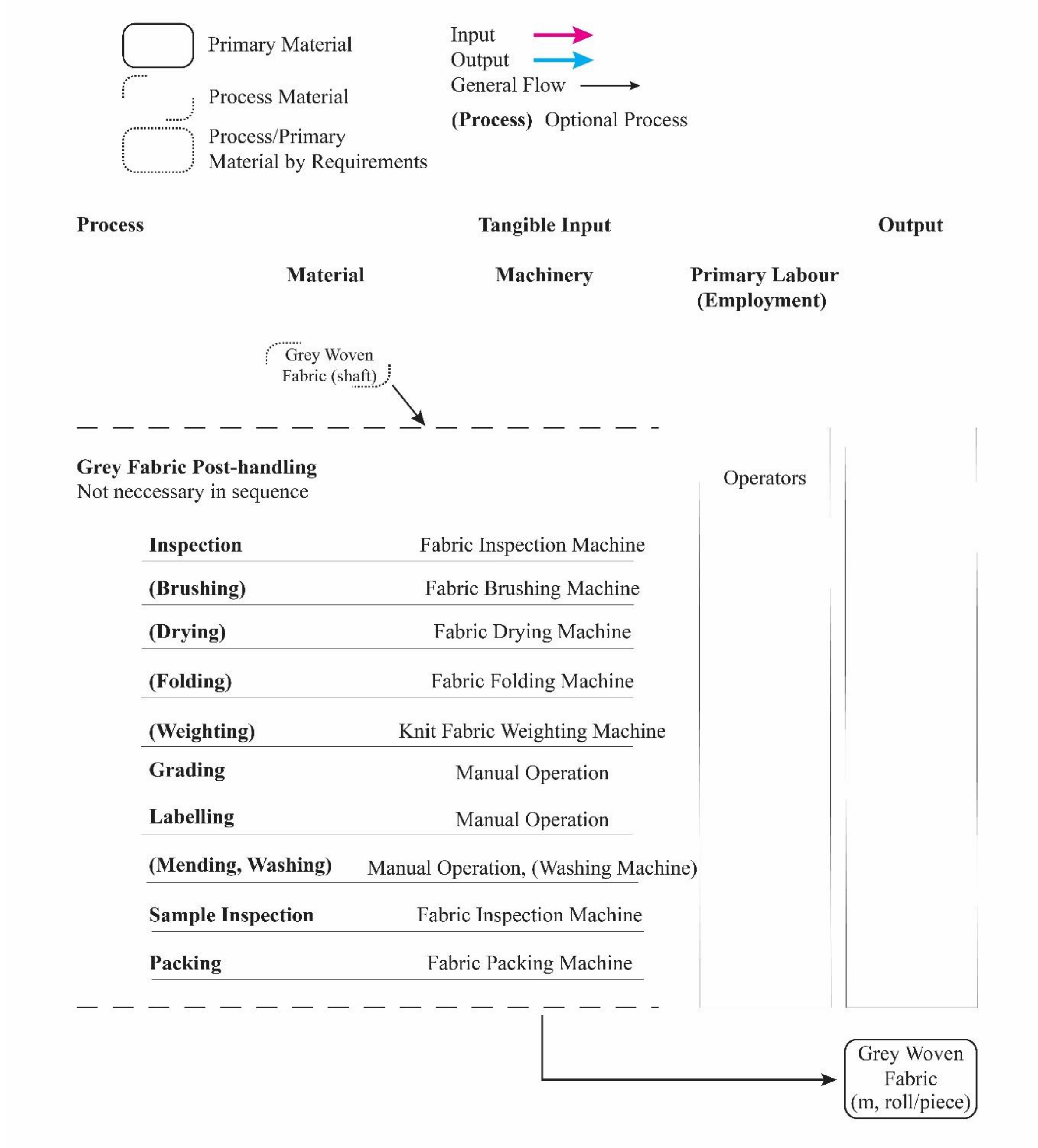
Figure 5.19 Fabric Knitting _Warp Knitting



Source: The Author

Once the grey fabric is removed from the weaving or knitting machines, it enters a post-handling stage that encompasses various processes, as shown in Figure 5.20. With this, the entire production of the grey fabric is complete, and the finished fabric is prepared for dyeing, printing, and finishing treatments.

Figure 5.20 Fabric Weaving & Knitting _ Post-handling



Source: The Author

5.2.5 From Grey Fabric to Final Fabric: Fabric Dyeing, Printing, and Finishing

The fabric dyeing, printing, and finishing phase is considered to have the most significant environmental impact among clothing production stages, involving the release of a substantial amount of chemicals through water and air. Addressed specifically in the European Commission's Best Available Techniques (BAT) Reference Document for the Textile Industry, dated 2023, are the industry's premier techniques designed to tackle this

very issue.
Fabric dyeing, printing, and finishing facilities are classified according to the type of grey fabrics they specialize in, concentrating on the production of specific materials: cotton/ramie/polyesters (including other synthetic fabrics) and their blends, wool, silk, and reproduction dyeing and finishing. The process of dyeing, printing, and finishing cotton grey fabric involves a series of machinery and processes that convert raw cotton fabric into finished products ready for garment manufacturing.

In general, factories concentrate solely on specific types of fabrics that fall within their production specialization, which includes optimizing the use of equipment, labour, and material resources that limited by plant size. For example, a 30,000,000 meters cotton fabric dyeing, printing, and finishing factory's product range can be the following (Table 5.3):

Table 5.3: Product Range of 30 million Meters Cotton Fabric Dyeing, Printing, and Finishing Factory

Product Range	**Annual Output (m)**
Bleached Cotton Plain Weaving Fabric	4,000,000
Dyed Cotton Poplin	6,000,000
Printed Cotton Poplin	2,000,000
Dyed Cotton Velvet	2,000,000
Printed Cotton Crepe	8,000,000
Bleached Cotton/Spandex Elastic Fabric	1,000,000
Double-Layer Printed Cotton	1,000,000
Printed Linen/Cotton Blend Plain Weaving	1,500,000
Dyed Polyester/Cotton Blend Plain Weaving	4,000,000
Dyed Rayon Twill	500,000

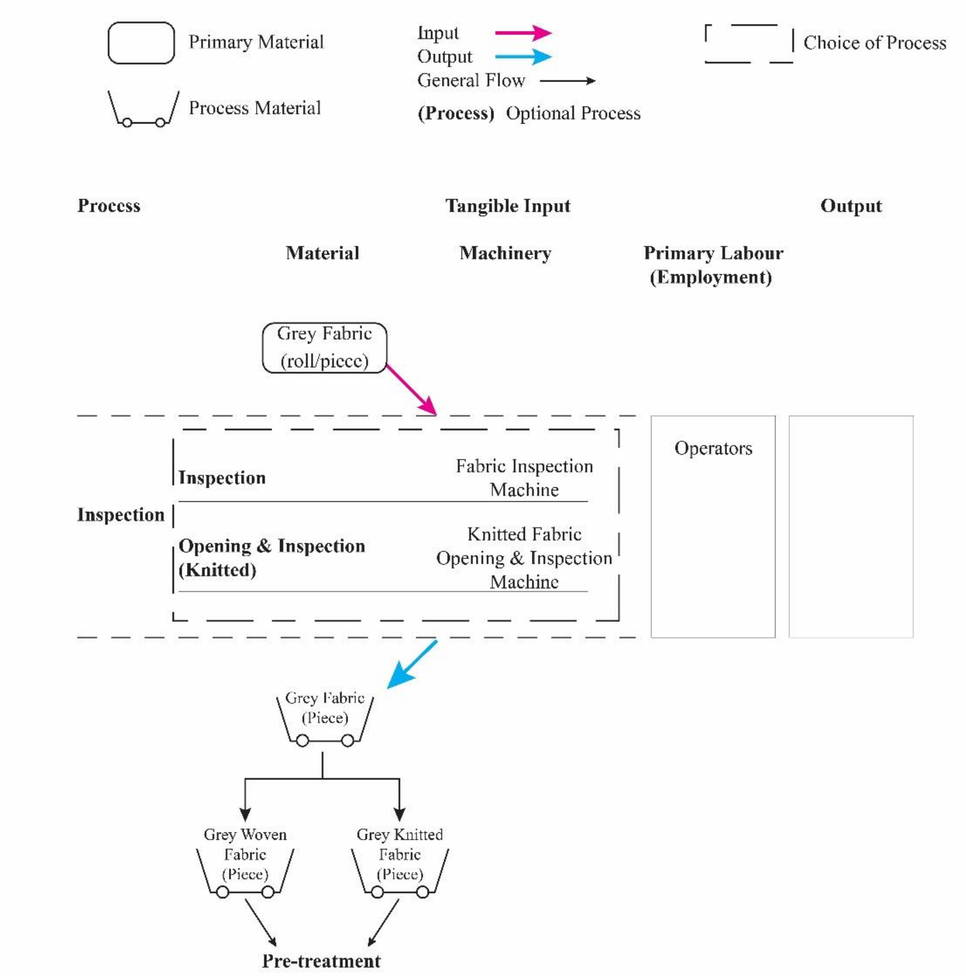
Source: Dyeing and Finishing Process Design (Textile textbook in Chinese)

Figure 5.21-5.27 depicts the transformation process of grey cotton fabric into white, coloured, or printed material, characterized by distinctive appearances, tactile experiences, and additional unique attributes. The diversity in processing methods can significantly influence the end product's quality and operational expenses, including energy and water usage, which in turn affect profitability. Regrettably, environmental impact is frequently disregarded by decision-makers when evaluating alternative processes.

The dyeing, printing, and finishing of fabric typically encompass six well-defined steps: inspection of the raw grey fabric, pre-treatment, dyeing, printing, post-treatment finishing, and handling of the finished product. Essential to any fabric treatment, the stages of pre-treatment, finishing, and finished product handling enable the production of white fabric. Coloration and printing are necessary only when the final fabric is to be produced in hues other than white or when print patterns are mandated. It is crucial to underscore that while woven and knitted fabrics undergo many similar processes, they are processed within their distinct systems and necessitate equipment tailored specifically for each type.

Figure 5.21 illustrates the inspection process prior fabric's pre-treatment.

Figure 5.21 Woven & Knitted_ Inspection Prior Pre-treatment

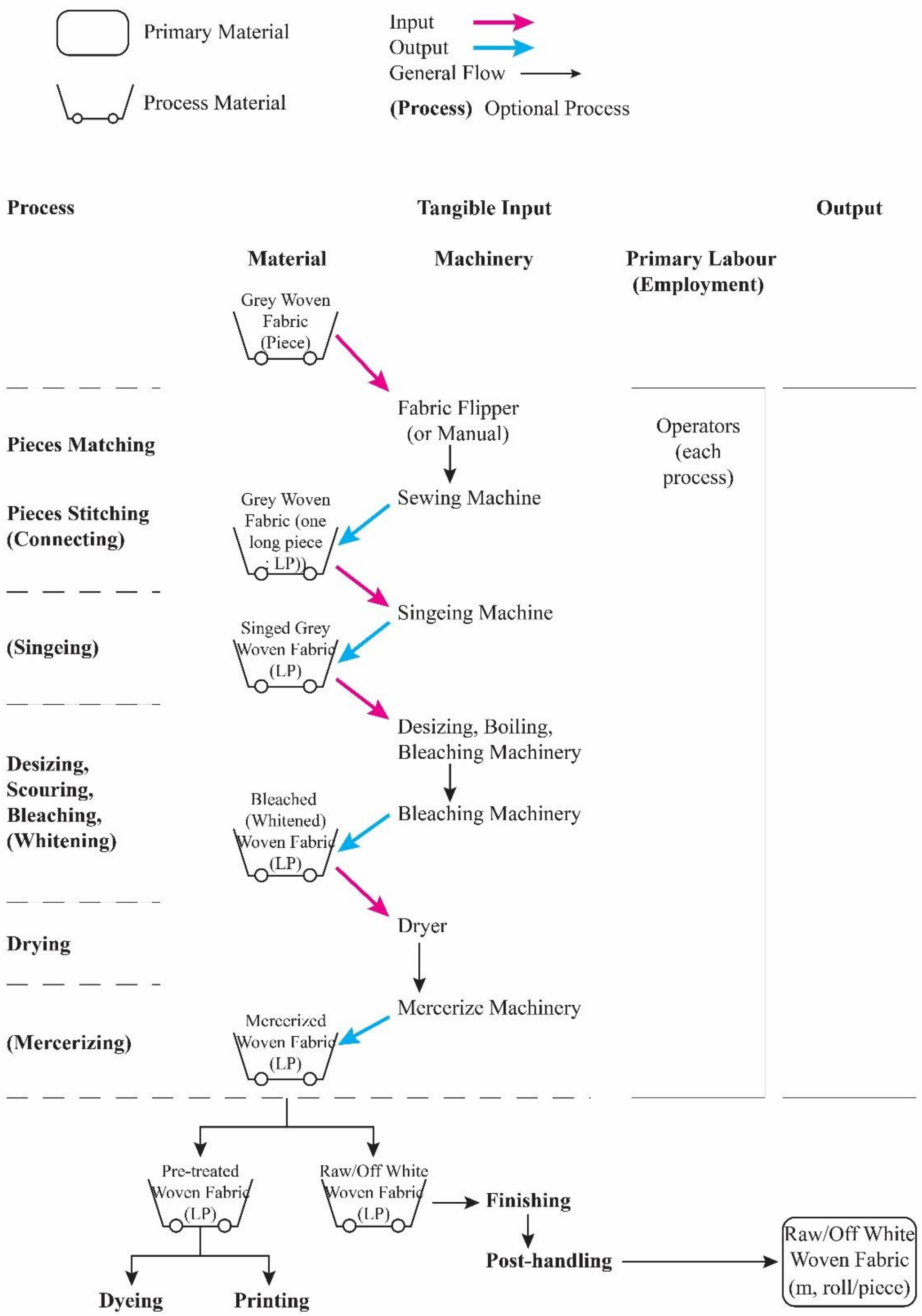


Source: The Author

Raw cotton fabric commonly bears impurities, including sizing agents like starch, as well as waxes and oils. The pre-treatment process is essential for purging these elements and enhancing the fabric's inherent qualities, thereby facilitating effective dyeing or printing, or potentially both. This preliminary step is crucial for attaining the final fabric's desired quality benchmarks. For woven cotton fabrics, a variety of pre-treatment and dyeing machines utilizing different methods are available. In contrast, for knitted fabrics, both pre-treatment and dyeing can be carried out using a single machine known as a dyeing vat.

Figure 5.22 features the woven fabric pre-treatment processes.

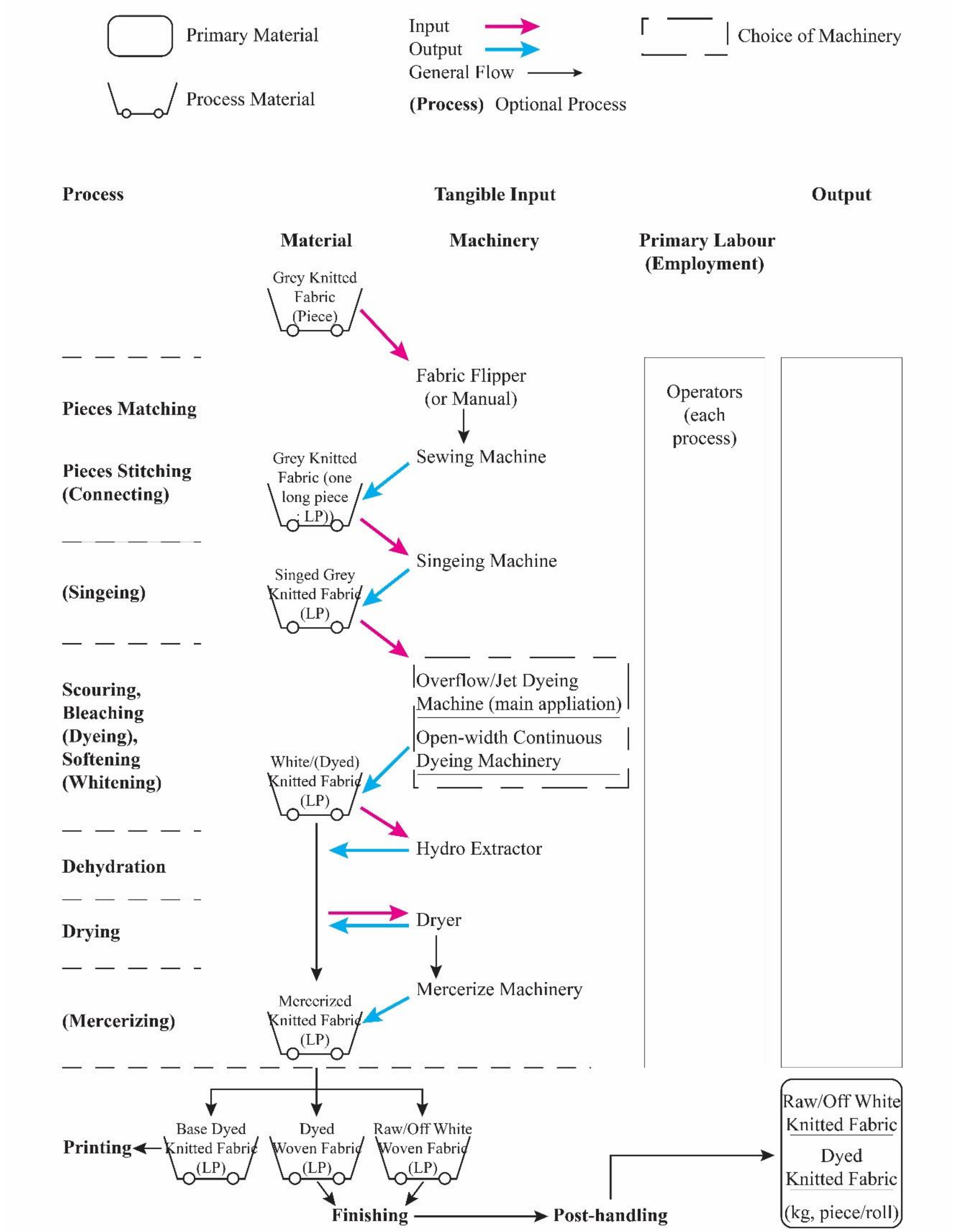
Figure 5.22: Fabric Printing, Dyeing, and Finishing_Woven Cotton _ Pre-treatment



Source: The Author

Figure 5.23 depicts knitted fabric pre-treatment and dyeing processes.

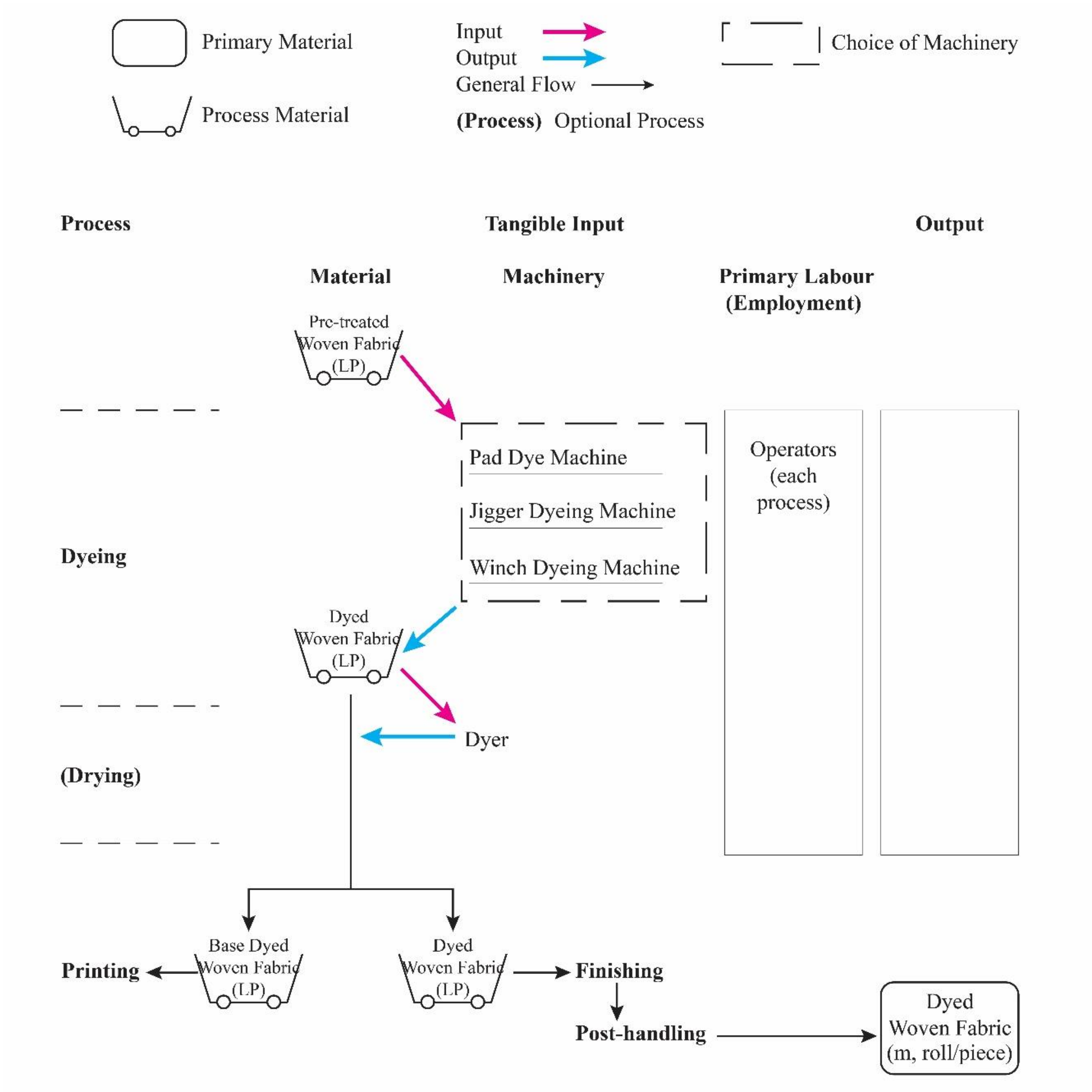
Figure 5.23: Fabric Printing, Dyeing, and Finishing_Knitted Cotton _ Pre-treatment & Dyeing



Source: The Author

Figure 5.24 featuring woven fabric dyeing processes.

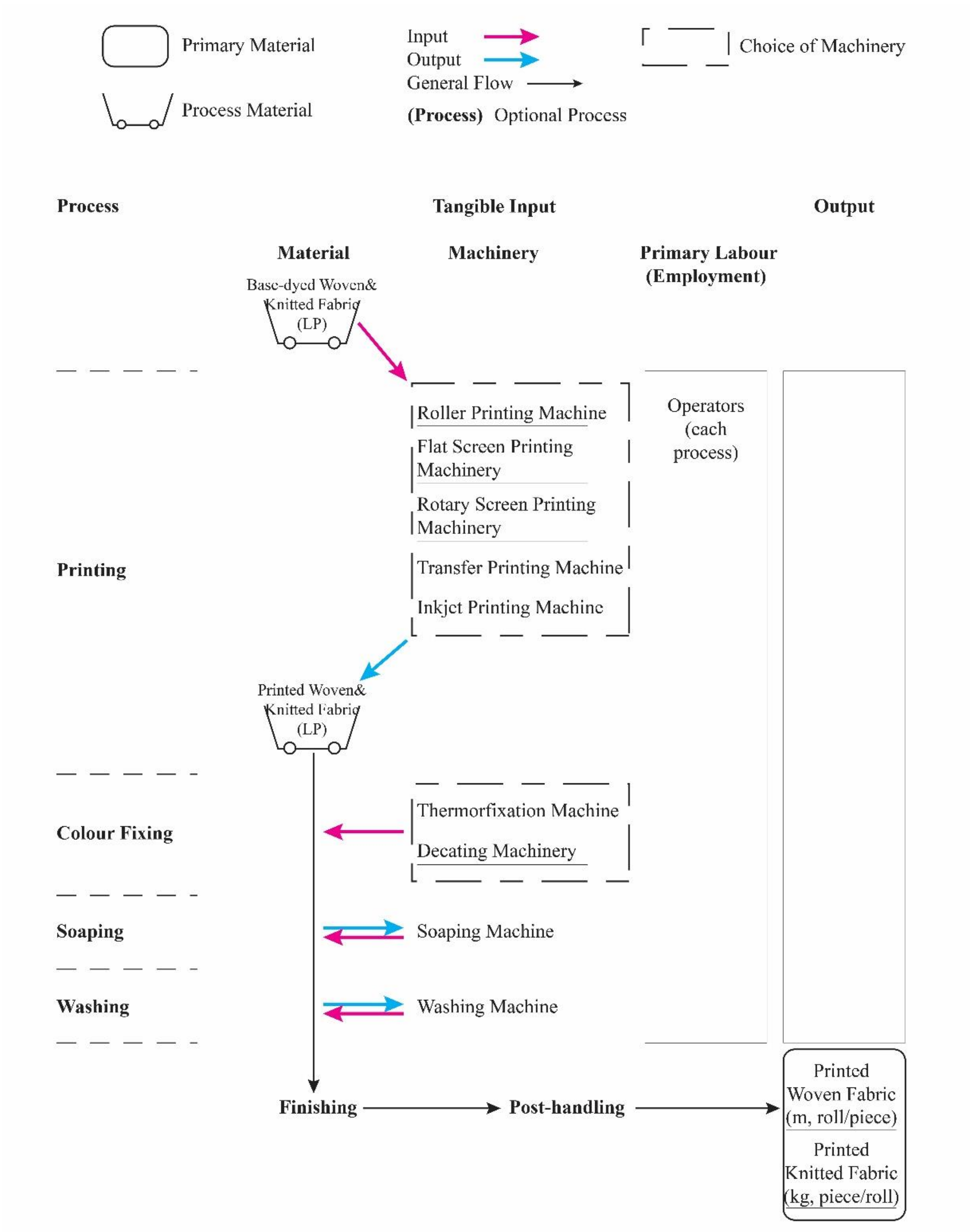
Figure 5.24: Fabric Printing, Dyeing, and Finishing_Woven Cotton _ Dyeing Process



Source: The Author

Pre-treated woven and knitted fabrics can be directly printed with patterns. However, it is common for fabrics to be dyed a base color before undergoing printing processes. Figure 5.25 illustrates the printing processes.

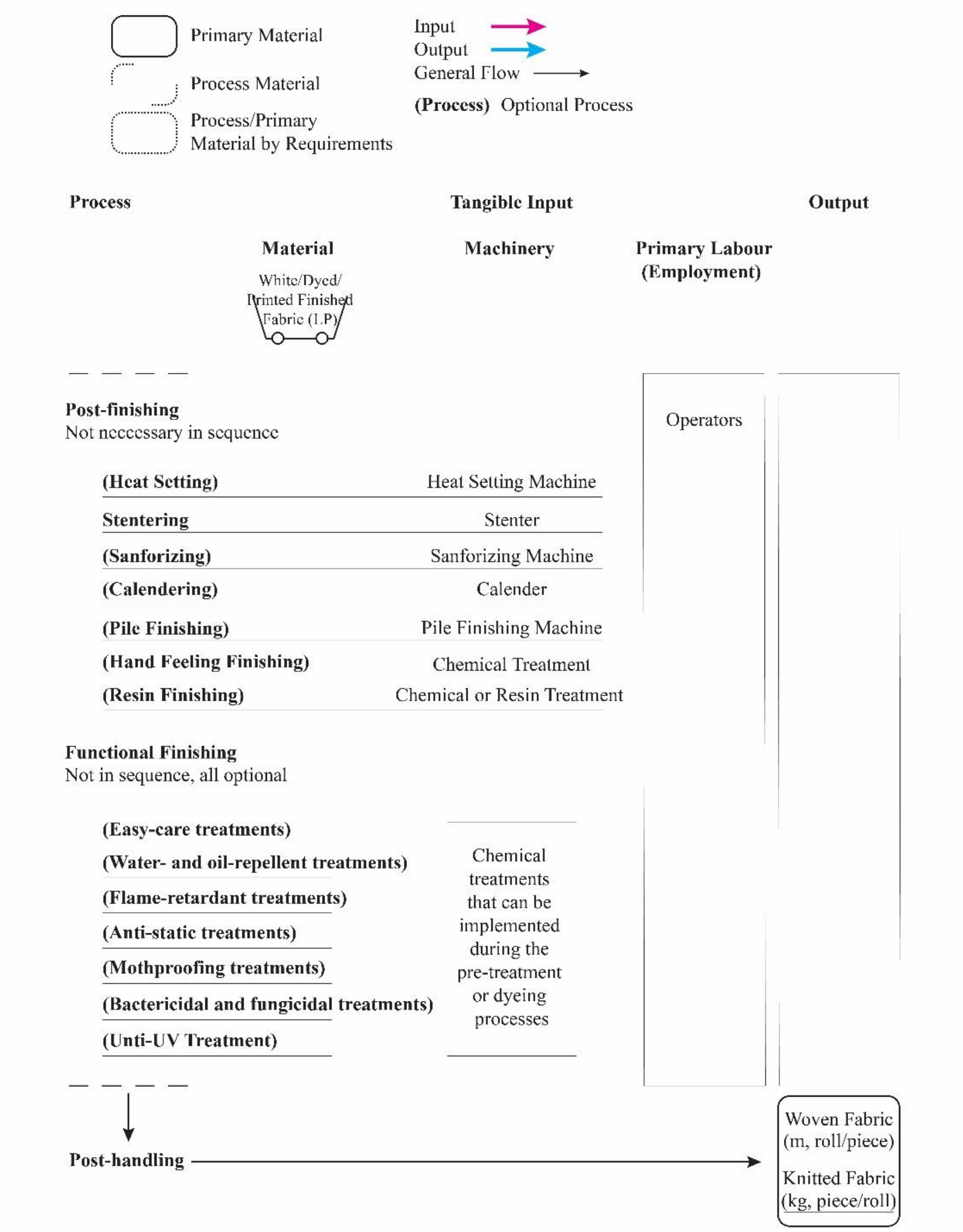
Figure 5.25: Fabric Printing, Dyeing, and Finishing_Woven&Knitted Cotton _ Printing Process



Source: The Author

Fabric finishing processes are designed to enhance the appearance, performance, and tactile qualities of fabrics. These processes can be broadly categorized into two types: post-finishing and functional finishing. The selection of post-finishing techniques varies depending on the type of fabric and primarily aims to stabilize the fabric's dimensions while endowing it with the desired texture and aesthetic appeal. Functional finishing, on the other hand, caters to specific applications. For instance, outdoor workwear often requires UV protection treatment as a standard functional finish. Figure 5.26 illustrates the fabric finishing processes.

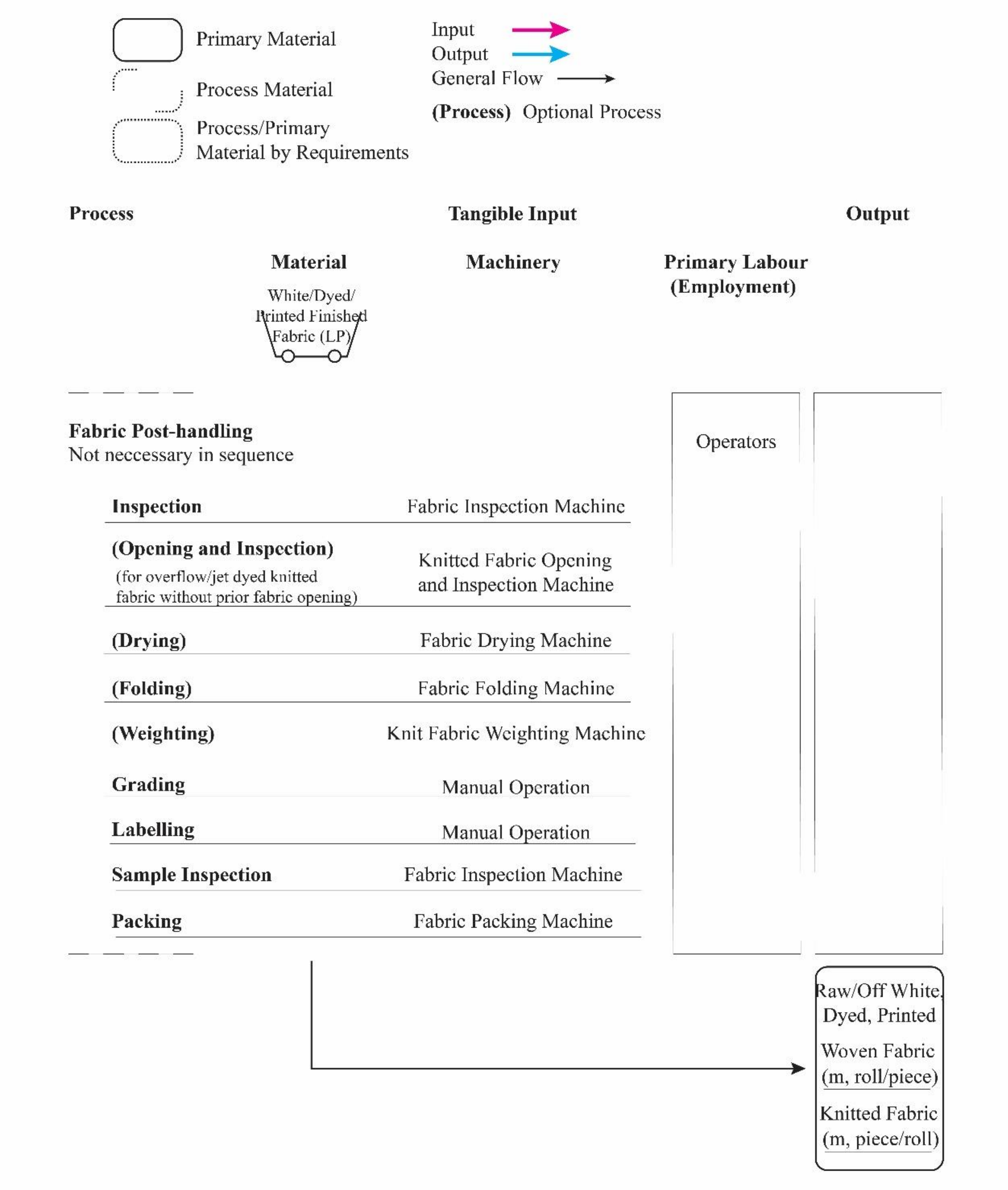
Figure 5.26: Fabric Printing, Dyeing, and Finishing_Woven&Knitted Cotton _ Finishing Process



Source: The Author

Ultimately, the fabric destined for garment production is refined through a series of post-treatment processes. As depicted in Figure 5.27, upon the completion of these treatments, the fabric attains its final form, ready for shipment to the garment manufacturer in accordance with the terms of trade agreements. However, it is quite common in industry practice for the fabric dyeing, printing, and finishing factory to be under the management of a fabric trading agent who oversees the entire production process from raw yarn to finished fabric. Subsequently, this trading agent assumes responsibility for coordinating with the garment manufacturer.

Figure 5.27: Fabric Printing, Dyeing, and Finishing_Woven&Knitted Cotton _ Post-handling Process



Source: The Author

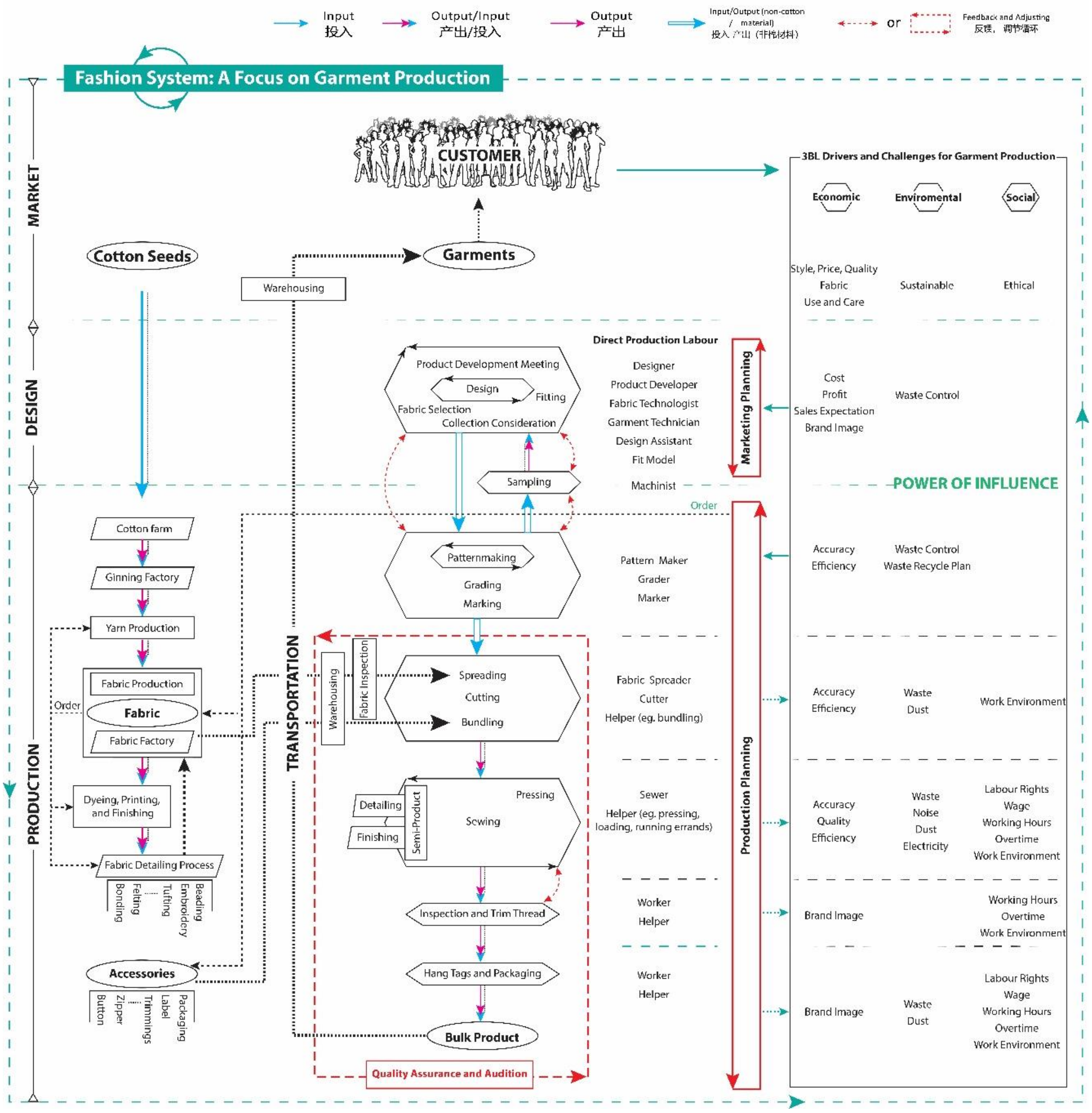
5.2.6 From Final Fabric to Garments: Cut & Sew Garments Production

Garment production, also known as apparel manufacturing, represents the final and arguably most intricate phase of clothing creation. The intricacy largely arises from the operational diversity across various garment types, a challenge that becomes especially pronounced in the global manufacturing arena. Essentially, all garments fall under one of two production methods: cut and sew, where fabric is crafted into wearable items, or knitwear production, which involves the direct transformation of yarn into garments.

Cut & Sew garment production factories are classified by garment type: uniform factory, men's wear factory, women's wear factory, kid's wear factory, down jacket factory, leather clothing factory, and other special clothing factory, etc. This research is specifically focused on the production of cotton material garments, and it will not include, for example, down jackets, leather apparel, or other specialized clothing production processes, as they are beyond the scope of this study. Men's wear can be further classified into suits, jackets, trousers, raincoats, coats, sportswear, uniforms, workwear, T-shirts, undershirts, pajamas, underpants, trunks, dressing gown, bathing wraps, etc. Women's wear can be further classified into blouses, dresses, costumes, jackets, slacks, coats, raincoats, sportswear, uniforms, workwear, corsets, bras, panties, bathing suits, pyjamas, nightgowns, housecoats, etc. Kid's wear can be further classified into suits, coats, jackets, trousers, shirts, dresses, blouses, undershirts, pyjamas, underpants, baby's underwear, bathing suits, bathing coats, etc. In general, factory is only focus on certain garments type that within their production speciality including optimizing utilize of the equipment, labour, and material resources. For instance, there are shirt factories that exclusively produce shirts.

Generally, a factory focuses on a specific range of garments to best manage their production, including optimal utilization of equipment, labour, and capital resources. The production process and it's position in the whole fashion system, however, is similar across all cut & sew garment production factories and depicted in Figure 5.28.

Figure 5.28: The Fashion System – A Focus on Garment Production



Source: The Author

Although different types of garments, or even individual garments are going through the same process, the execution of the process can vary based on fabrics and accessories (materials), equipment (machines), work skills (labour), and the method of management (entrepreneurship). This research investigates the production of a 100% 40s cotton shirt in Chapter 6 to explain the complexity of cotton clothing production. It is hypothesised that there are different impacts among different garment production approach. During the intended PhD stage for this research, further case studies in industry will be conducted to explore these.

5.2.7 From Yarn to Knitwear: Knitting Garments Production

Knitwear production is relatively straightforward. Customized yarn is directly knitted into garment pieces using a knitting machine, and these pieces are subsequently assembled into complete garments through a seam-joining knitting machine. The garment pieces then undergo an ironing and finishing process, followed by post-handling procedures similar to those in cut & sew garment production. There are several knitwear garment factories in Australia, which will be explored further during the intended PhD stage.

5.3 Data Records through Input-Output Production Tables

The input-output production flowcharts for cotton clothing manufacturing, from seed to garment, visually depicted the major data boundaries and their interconnections throughout the processes. The quality of these connections is to be demonstrated through the input-output production tables, which will facilitate further analysis to develop substantive theories before abstract theories can emerge. As outlined in Chapter 3, the methodology requires case studies to perform this task, designated for research at the proposed PhD level. Nevertheless, Chapter 6 introduces a hypothetical case study set within an industrial context, showcasing how production data can be presented in specific instances.

5.4 Addressing Triple Botton Line Sustainability through Production Analysis

Similarly, this section is designed for research at the proposed PhD level, with Chapter 6 offering a demonstrative example.

Chapter 6 The Production Impact of Australian Cotton

Chapter 5 introduced a comprehensive Input-Output Production Flowchart for cotton clothing, detailing the operations of the production chain and how key inputs and outputs interact through various stages. This chapter features a hypothetical case study crucial for developing Input-Output Production Tables, Production Economic Measures, and Production Environmental Measures, demonstrating their real-world relevance through practical application. This case study involves an input-output production analysis of Australian cotton, evaluating its triple bottom line impact on a global scale.

Production operations may vary based on specific products, material properties, the enterprises involved, and timing. The volume of documentation tied to the production chain also varies significantly, from a handful to hundreds of documents, largely influenced by the management practices of the participating entities. Moreover, the complexity of the production system means that a clear vision of the current status of production - specifically, the volume and enterprises of materials converted into each product category in the market - is lacking. Therefore, explanations, assumptions, and references are essential to validate a case study, standardize data and accommodate real-time production fluctuations in case studies. Without such approach, meaningful analysis of production dynamics would be impractical.

6.1 Explanation, Assumption and Reference

The explanations, assumptions, and references are described in the following.

1. It is assumed that all Australian cotton is allocated for manufacturing 100% casual cotton shirts, specifically in style code ACSHIRT_01 and size 10. The reasoning behind selecting this particular shirt for the production evaluation sample is detailed in the subsequent section (6.2).
2. The case study examines the production of this shirt from cotton seeds to finished garments, covering several industry segments outlined in Chapter 5. These segments include Australian cotton farming, cotton ginning, yarn production, grey fabric production, fabric dyeing, printing and finishing, and garment production.
3. The shirt production incorporates selected processes from those documented in the Input-Output Production Flowcharts for Cotton Clothing Production. However,

specific production data, which could be collected from individual enterprises in a conducted case study, is lacking. As a result, secondary or estimated data will be utilized. This data may not directly relate to the specific processes but will serve to fulfill the evaluation's purpose, ensuring that the developed methodological tools are applicable in real-world scenarios.

4. The production documentation included in this analysis is limited to essential elements such as materials, machinery, and direct labour. Documentation related to broader entrepreneurial aspects, such as enterprise production planning and labour management, is omitted. Additionally, the provided documents may have been modified from their original industrial formats to better serve the analytical process.
5. The data used represents a hypothetical scenario typical of production environments and may also mirror actual data from various global production scenarios. However, the data might need to be justified from the original source due to the absence of actual data. The interpretation of data justification and documentation of data sources is complex and requires careful consideration and integration to future endeavours.
6. A brief justification of the data is provided for the production data of Australia cotton farming and ginning in their respective sectors, linked to a summary of the data source in Table 6.1.

Table 6.1: Data Source List for Australia Cotton Farming and Ginning

Table: Data Source List Document Code: A	Version: V1	Date:	10/08/2024
Data Title	**Key Data Owner /Author/Editor**	**Reference Code**	**Data(d)/or Publication(p) Year**
Australian Furrow Irragated Cotton Budget 2023/2024	Cotton Australia	DCF01	2023 (p)
Australian Cotton Sustainability Report 2019	Cotton Australia	DCF02	2019 (p)
Australian Cotton Industry Leadship Websites CSIRO; CRDC; Cotton Australia; MyBMP; CottonInfo; CSD	Cotton Australia	DCF03	NA
Cotton World Markets and Trade Report 2024	United States Department of Agriculture	DCF04	2021 (p)
Benchmarking report of direct energy consumption in Australian irrigated cotton production - Executive Summary	Cotton Australia	DCF06	2015 (P)
Benchmarking water productivity of Australian irrigated cotton – 2021 results	NSW DPI Water Productivity Benchmarking Team	DCF08	2021 (p)
Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)	ABARES	DCF09	NA
Energy uses for cotton ginning in Australia	Siti A. Ismail a , Guangnan Chen b, *, Craig Baillie b , Troy Symes b	DCG01	2010 (p)
Midkin gin field data	AFF (Australian Food & Fibre)	DCG02	2023 (d)
Cotton Ginning Emission Factor Documentation for AP-42	for the United States Environmental Protection Agency	DCG03	1996 (p)
Engineering and Ginning	Derek P. Whitelock, Michael D. Buser*, J. Clif Boykin, and Gregory A. Hol	DCG04	2015 (p)
Comparing running costs of diesel, LPG and electrical pumpsets	DPI	DAL02	2016 (p)
Measuring Cotton Consumption: BCI Conversion Factors and Multipliers	Better Cotton Initiative	DAL03	2020 (p)
www.sinotex.cn/ www.alibaba.com www.google.com for cotton material and garment characters and price reference	The Website	DAL05	NA
Empirical data of practitioners from online post, verbal communication, etc.	Empirical data collected from practitioners through online posts, verbal communications, and other methods	DAL06	
IBISWorld Reports	IBIS World	DAL07	

Source: The Author

7. The production data for cotton yarn, grey fabric, fabric dyeing, printing, and finishing, as well as garment production, is justified based on data from Table 6.2. Although this justification process resembles that for cotton farming and ginning data, it is more complex and therefore more difficult to detail in this thesis and has been omitted as a result.

Table 6.2: Data Source List for Cotton Yarn to Garment Production

Table: Data Source List
Document Code: BH Version: V1 Date: 10/08/2024

Data Title	Data Title (Chinese/Ori.)	Key Data Owner /Author/Editor	Reference Code	Data(d)/or Publication(p) Year
Cotton Spinning Manual (3rd Edition)	棉纺手册（第三版）	上海纺织控股（集团）公司 棉纺手册（第三版）编委会	DCY01	2004 (p)
Spinning Systems and Equipment	纺纱系统与设备	郁崇文主编	DCY02	2005 (p)
Weaving Principles	织造原理	郭兴峰 主 编	DCF01	2014 (p)
Weaving Engineering	织造工程	牛建设 主编	DCF02	2015 (p)
Knitting Technology (2nd Edition)	针织工艺学（第二版）	贺庆玉，刘晓东 主 编	DCF03	2009 (p)
1712 Cotton Weaving and Processing Production Pollution Index	1712 棉织造加工行业系数手册	Ministry of Ecology and Environment of the People's Republic of China (MEEPRC)	DCF04	2021 (p)
Cotton Textile Mill Design (2nd Edition)	棉纺织工厂设计（第二版）	钱鸿彬主编	DCY03	2007 (p)
Cotton Textile Mill Design	棉纺织厂设计	李辛凯主编	DCY04	1980 (p)
Vocational Skills Training Materials for the Cotton Textile Industry	棉纺织行业职业技能培训教材	中国棉纺织行业协会 编著	DCY05	2022 (p)
Best Available Techniques (BAT) Reference Document for the Textile Industry		Roth, J., Zerger, B., De Geeter, D., Gómez Benavides, J., Roudier, S.	DPF01	2023 (p)
Cotton Textile Dyeing, Printing, and Finishing Production Pollution Index	1713 棉纺织及印染精加工行业系数手册	Ministry of Ecology and Environment of the People's Republic of China (MEEPRC)	DPF02	2021 (p)
Textile Dyeing and Finishing Technology (3rd Edition)	纺织品染整工艺学（第三版）	范雪荣主编	DPF03	2017 (p)
Dyeing and Finishing Process Equipment (3rd Edition)	染整工艺设备（第三版）	王炜主编	DPF04	2020 (p)
Practical Production Management for Printing and Dyeing Enterprises	印染企业生产管理实务	张彭主编	DPF05	2021 (p)
Printing and Dyeing Enterprise Management Manual	印染企业管理手册	无锡市明仁纺织印染有限公司	DPF06	2007 (p)
Dyeing and Finishing Process Design	染整工艺设计	李锦华 主 编	DPF07	2008 (p)
Garment Production Processes and Equipment (3rd Edition)	服装生产工艺与设备（第三版）	姜蕾，汪苏编	DCG01	2019 (p)
Garment Production Management (5th Edition)	服装生产管理（第五版）	万志琴，宋惠景编	DCG02	2018 (p)
Garment Factory and Production Line Design	服装厂与生产线设计	王雪筠主 编	DCG03	2013 (p)
Specifications for continuous emissions monitoring of SO2, NOX, and particulate matter in the flue gas emitted from stationary sources (HJ 75-2017)	固定污染源烟气（SO2、NOX、颗粒物）排放连续监测技术规范	Ministry of Ecology and Enviroment of the People's Republic of China (MEEPRC)	DAL01	2007 (p)
Comparing running costs of diesel, LPG and electrical pumpsets		DPI	DAL02	2016 (p)
Measuring Cotton Consumption: BCI Conversion Factors and Multipliers		Better Cotton Initiative	DAL03	2020 (p)
Industrial Pollution Accounting	工业污染核算	毛应准主编	DAL04	2014 (p)
www.sinotex.cn/ www.alibaba.com www.google.com for Yarn, Fabric, Garment price reference		The Website	DAL05	NA
Empirical data of practitioners from online post, verbal communication, etc.		Empirical data collected from practitioners through online posts, verbal communications, and other methods	DAL06	
IBISWorld Reports		IBIS World	DAL07	

Source: The Author

6.2 Rationale for the Evaluation of Casual Cotton Shirt Production

The cotton shirt stands as a primary end product within the broad spectrum of items that Australian cotton is made to, which also includes T-shirts, denim, towels, and bed sheets, among others. For more precise applications, Australian cotton is employed in the creation of medium to fine weight carded and combed knits, drill fabrics, standard bed linens, and towels characterized by a yarn count ranging from 100 to 30 tex (Ne 6 to 20). It is also utilised for medium to fine weight combed knits and woven fabrics with up to 50 tex (up to Ne 12) used in shirting and bed linens, as well as finer weight combed knits and medium to fine weight combed woven fabrics intended for high-count pile bed linens, reaching up to 30 tex (up to Ne 20). (Cotton Australia 2022)

The rationale for selecting casual shirt production to represent Australian cotton textile products in estimating the impact of Australian cotton is that it is likely the most fitting garment type for an authentic representation, considering its production characteristics and fabric requirements. Observations in the Australian market reveal that Australian cotton T-shirts and knit tops have a significant market presence. The range of fabric yarn counts for Australian cotton garments that hold the largest market share is comparable to that of casual cotton shirts. In contrast, the fabric yarn count for business shirts falls within a higher-end spectrum, necessitating more sophisticated technical expertise. For instance, the yarn count for business shirts typically surpasses 7.5 tex (Ne 80 and above), while it can reach up to 30 tex (Ne 20 and above) for casual shirts.

When searching "Australian cotton shirt" on Google, a branded Australian cotton shirt appears as the top result. This shirt was designated as the case study for an input-output production analysis, labelled ACSHIRT_01, chosen for its design and production simplicity in both garment construction and fabrication, positioned between knit tops and high-end woven garments in terms of production process and technique. The sales promotion images of this shirt presented below, sourced from the brand's website. Ethical considerations dictate that the brand remains anonymous.

Figure 6.1: Image of Case Study Shirt (ACSHIRT_01)

Source: public assessable website, brand name is omitted.

6.3 Shirt ACSHIRT_01 Production Technical Package and Materials

6.3.1 Technical Package: Pattern, and Pattern Layout

As outlined in Chapter 3 within the Research Design section 3.3, the production analysis excludes the design phase. Therefore, following the finalization of a style, the chosen fabrics, trims, and accessories are confirmed and documented in the tech pack, a technical package that may include one or more of the following: a style sheet, size chart or specification sheet, and production guidelines. The pattern for the shirt, along with its layout, is also finalized, subject to minor alterations as per the label's feedback on the confirmed design sample. An initial calculation of material usage has been performed to ascertain the trading price of the garment.

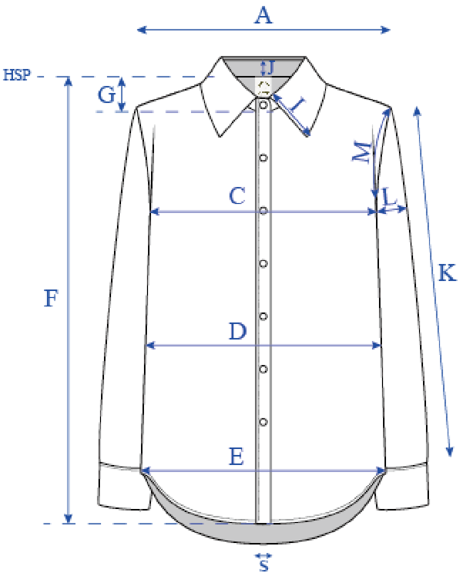
The information verified in the design and pattern-making phases streamlines the garment manufacturer's initiation of production planning. This encompasses ordering and preparing materials, scheduling and allocating bulk cutting, sewing, as well as pressing and managing the finished products.

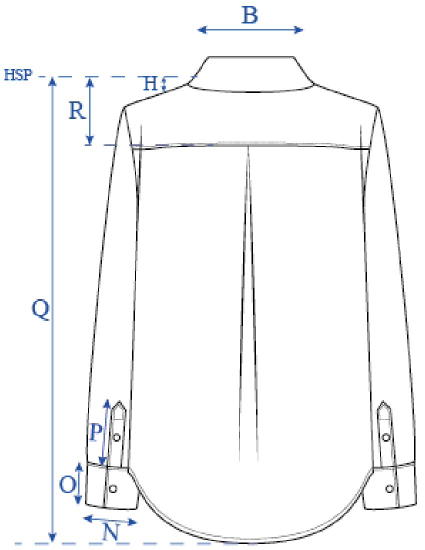
Table 6.3 displays the tech pack for style ACSHIRT_01

Table 6.3: ACSHIRT_01 Specification

	Factory	AC Partners	Style	Cotton Shirt	ACSHIRT_01
	Contact	Mia Zhou			
	Document No.	Spec ACSHIRT_01		Date	7/05/2024

Ref	List	Measurements (In cm)	6	8	10	12	14	16	18	Grade	TOL±
FR	A	Shoulder Breadth 肩宽（直量缝到缝）	38.3	39.5	**40.7**	41.9	43.1	44.3	45.5	1.2	1
	B	Neck Width 领宽	16.9	17.5	**18.1**	18.7	19.3	19.9	20.5	0.6	1
	C	1/2 Chest 1/2胸围(underarm to underarm) 半胸围（下夹到下夹）	49.5	52.0	**54.5**	57.0	59.5	62.0	64.5	2.5	1.5
	D	1/2 Waist 1/2腰围	48.5	51.0	**53.5**	56.0	58.5	61.0	63.5	2.5	1.5
	E	1/2 Hem 1/2下摆	51.5	54.0	**56.5**	59.0	61.5	64.0	66.5	2.5	1.5
	F	FR Length From HSP 前身长	72.8	74.0	**75.2**	76.4	77.6	78.8	80.0	1.2	2
	G	Front Neck Drop 前领深	6.7	7.0	**7.3**	7.6	7.9	8.2	8.5	0.3	0.5
	H	Back Neck Drop 后领深	1.0	1.0	**1.0**	1.0	1.0	1.0	1.0	0	0.5
	S	CF Fly Width 门襟宽	2.8	2.8	**2.8**	2.8	2.8	2.8	2.8	0	0.5
CO	I	CF Collar Peak 翻领尖高	7.0	7.0	**7.0**	7.0	7.0	7.0	7.0	0	0.5
	J	CB Collar Stand Depth 后中领台高	2.8	2.8	**2.8**	2.8	2.8	2.8	2.8	0	0.5
SLV	K	Sleeve Length excl Cuff 袖长	55.4	56.0	**56.6**	57.2	57.8	58.4	59.0	0.6	1
	L	1/2 Upper Arm Width (from underarm) 1/2袖肥 (下夹处横量）	17.9	18.5	**19.1**	19.7	28.0	28.6	29.2	0.6	1
	M	1/2 Armhole Curve 1/2袖笼弯量	24.4	25.0	**25.6**	26.2	26.8	27.4	28.0	0.6	1
	N	1/2 Sleeve Opening 袖口系扣后	9.7	10.0	**10.3**	10.6	10.9	11.2	11.5	0.3	0.5
	O	Sleeve Cuff Depth 袖头高	6.0	6.0	**6.0**	6.0	6.0	6.0	6.0	0	0.5
	P	Sleeve Split excl. Cuff	12.0	12.0	**12.0**	12.0	12.0	12.0	12.0	0	1
BK	Q	CB Length 后中衣长	78.8	80.0	**81.2**	82.4	83.6	84.8	86.0	1.2	2
	R	CB Yoke Depth 后过肩高	15.0	15.0	**15.0**	16.0	16.0	16.0	16.0	/	1





Confirmed Design Sample

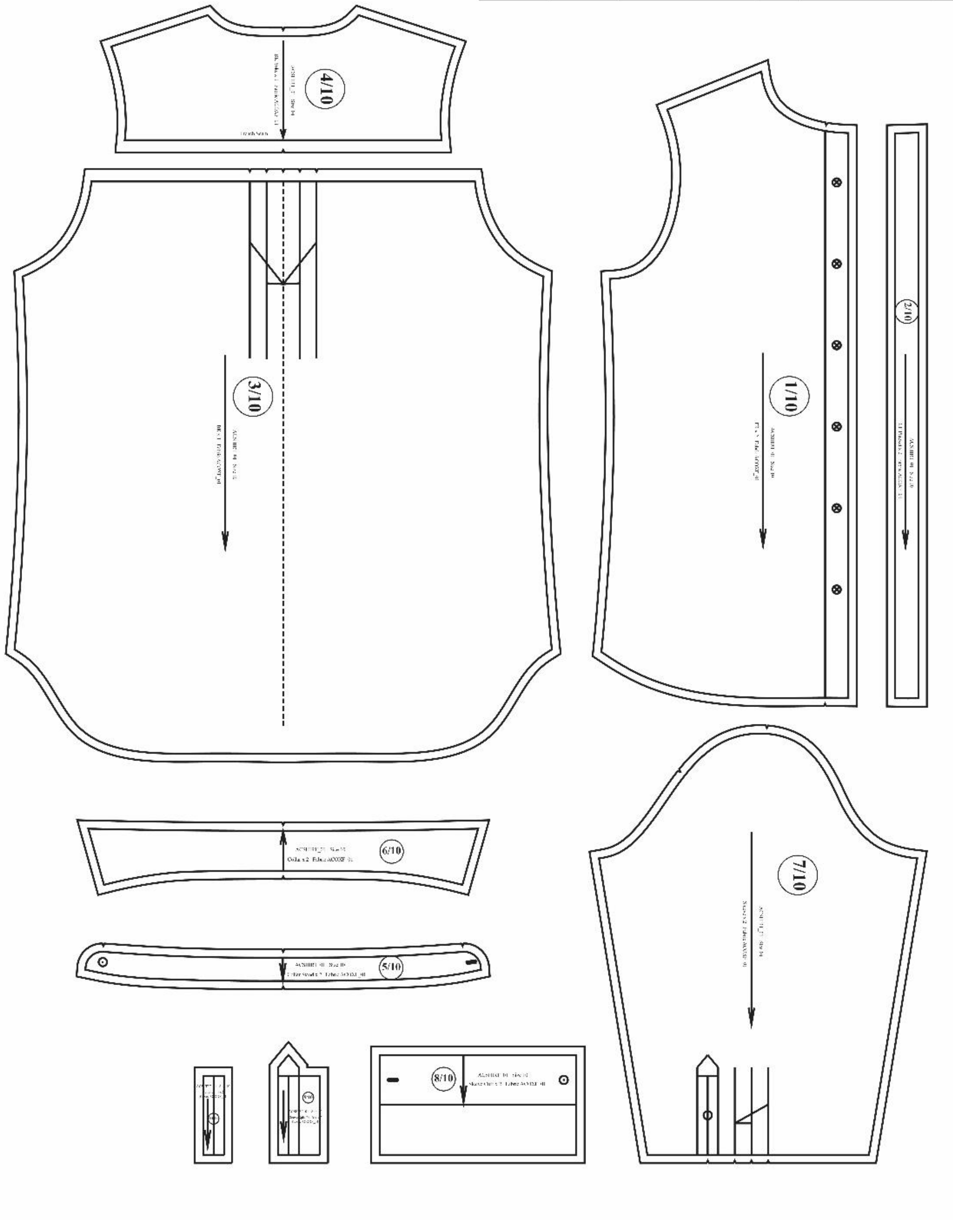
Fabric （面料）	Position（部位）	Colour（颜色）	Usage（用量）		Cost(费用)
100% Australian cotton (澳棉全棉）	body（大身）	white（白色）	smpl size 10, fabric width 1.45m	1.235 m	21/m
non-woven interlining（无纺衬)	collar, CF fly, sleeve cuff（领、门襟、袖口）	white（白色）		0.3m	4/m
Trim（辅料）	**Position（部位）**	**Colour（颜色）**	**Usage（用量）**		**Cost(费用)**
button（纽扣）	CF placket, sleeve cuff（门襟/袖袢）	white（白色）	11		0.2/颗
100% Australian cotton 402# thread （澳棉402#线）	all（全件）	white（白色）			

Source: The Author

Table 6.4 shows the pattern document for the shirt.

Table 6.4: ACSHIRT_01 Size 10 Patterns

Style	Casual Cotton Shirt	Style Code	ACSHIRT_01	Size Range		6, 8,10, 12, 14, 16, 18	
Fabric	100% Australian Cotton	Fabric Code	ACOXF_01	Width	145cm	Weight	140gsm
		Size	10	Pattern Pieces	18	Fabric Usage	1.235m



1/10 Front (FR) x 2	2/10 Front Placket x 2	3/10 Back (BK) x 1	4/10 Back Yoke x 1	5/10 Collar Stand x 2
6/10 Collar x 2	7/10 Sleeve x 2	8/10 Sleeve Cuff x 2	9/10 Sleeve Split Placket x 2	10/10 Sleeve Split x 2

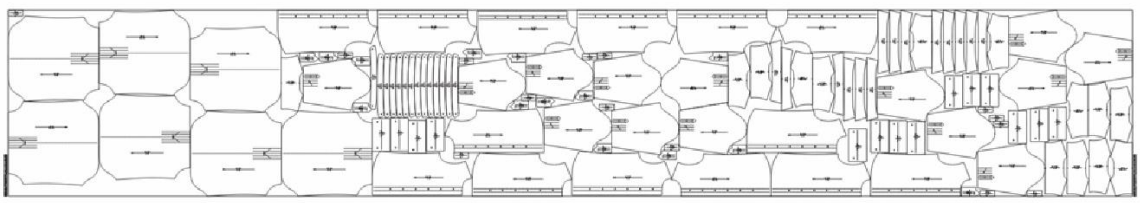
Source: The Author

Note: The drafts for individual patterns are commissioned works.

Table 6.5 displays the bulk cutting pattern mark for the shirt.

Table 6.5: ACSHIRT_01 Size 10 Bulk Cutting Marker

Style Code	Fabric	Fabric Width	Pattern Sets	Size/ SizeRange	Marked Pieces	Un-marked Pieces	Fabric Shrinkage		Fabric Usage in Length		
							Warp %	Weft %	Ttl	per Set	Rate
ACSHIRT_01	100% Cotton	145cm	7	10 /6-18	126		0	0	841.16 cm	120.17 cm	86.6%



Source: Commissioned Work

6.3.1 Material Properties: Fiber, Yarn & Fabric

<u>Cotton Fiber</u>

The Australian Cotton Shippers Association (ACSA) is responsible for compiling the annual data on the cotton fibre quality parameters of the Australian cotton crop. (Cotton Australia)

The properties of typical Australian cotton, grade strict middling and middling, is depicted in Table 6.6.

Table 6.6: Typical Australian Cotton Fiber Key Properties		
Length	1-5/32" – 1-1/4" (37-40) 29 mm – 32 mm	
Micronaire	G5	
Strength	29-34 GPT	
Uniformity	81-83	
Other Characteristics	•	Consistent quality
	•	Zero contamination
	•	Traceability from farm to mill
	•	Contract sanctity and reliable counterparties
	•	Strict adherence to International Cotton Association rules
	•	Fast shipping times and efficient, reliable delivery
Source: ACSA Cotton | About Australian Cotton (austcottonshippers.com.au)		

Industry-wide, it is recognized that the quality of cotton fibres is the fundamental determinant of fabric quality. Australian cotton is renowned for its superior quality, and in the eyes of

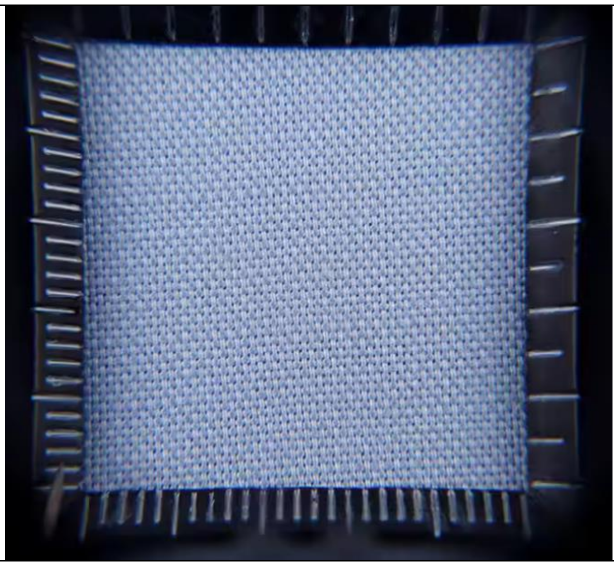
Chinese media, it is identified as a mark of high-quality cotton. Every bale produced in Australia is usually sold out.

To produce shirts, Australian cotton fibres are transformed into warp and weft yarns essential for fabric weaving, as well as threads crucial for garment construction. The subsequent sections will provide estimates on the quantity of fibres required for warp yarn, weft yarn, and sewing threads. It should be noted that data pertaining to accessories and embellishments are not encompassed within this research scope.

Cotton Yarn & Fabric

The online marketing for Australian cotton fabrics is quite limited, which is probably because fabrics made entirely or partially from Australian cotton are typically produced to order. Within the small selection of Australian cotton shirts that appear on the first three pages of Google when searching for "Australian cotton shirts," many are made of Oxford cloth. Information regarding Australian cotton Oxford fabric is scarcely available online, if at all. However, its production technique is consistent with that of general cotton Oxford fabric, and this information is linked to the fabric used for the shirt ACSHIRT-01, coded as ACOXF-01. The properties of the ACOXF-01 fabric are outlined in Table 6.7.

Table 6.7: Fabric ACOXF-01 Key Properties



Property Type	Description
Product Name	Oxford Shirt Fabric
Product Code	ACOXF_01
Material	100% Cotton
Pattern	Plain Dyed, Customized Color
Yarn Type	Combed
Yan Technics	Spun Yarn
Yarn Count	40x32/2 (14.5tex) x (18tex/2)
Density	120*50
Thickness	Medium Weight
Weight	140Gsm
Fabric Technics	Oxford Woven
Width	57/58"
Packaging Details	In Roll
Supply Ability	100000 Kilogram/Kilograms Per Day
Supply Type	Make-To-Order
Port	Shanghai Port

Source: Popular 100 % Cotton Men/women Oxford Shirt Fabric Cotton Fabric - Buy Popular Men/women Shirting Fabric 100 % Cotton Oxford Shirt Fabric,100% Cotton Oxford Fabric,Oxford Shirt Fabric Product on Alibaba.com

Data essential for calculating yarn consumption and the associated costs for producing one shirt are compiled in Table 6.8.

Table 6.8: Yarn Consumption and Cost for Producing One Piece of Shirt ACSHIRT-01

Table: Yarn Consumption & Cost

Document Code: BB Version: V1 Date: 10/08/2024

Category		Code	Data H	Measure	Data Type (r,a,e,c,s)*	Reference/Formula
Finished Fabric (Dyed)	Fabric Structure	(6)	Oxford 2/1 Basket Weave			
	Width (m)	(7)	145	cm	s	Table 6.5
	Weight	(8)	140	g/m²	s	Table 6.7
	Piece Length (m)	(9)	40	m	s	Table 6.7
	Usage/Shirt	(10)	1.20	m	r	Table 6.5
Grey Fabric Parameter						
Yarn Count	Warp Yarn	(12)	14.5	Tex	s	Table 6.7
	Weft Yarn	(13)	18 x 2		s	Table 6.7
Density	Warp Yarn	(14)	120	/inch	s	Table 6.7
	Weft Yarn	(15)	50		s	Table 6.7
Warp Yarn Count	No. of Yarn	(16)	6960		c	==H14/2.5*H7
	Selvage	(17)	same picks/dent		a	Table 6.7
Shrinkage	Warp Yarn	(18)	11.0%		r,a	DCY04, p333
	Weft Yarn	(19)	2.2%		r,a	DCY04, p333
Stretch	Warp Yarn	(20)	1.2%		r	DCY04, p333
	Weft Yarn	(21)	0.0%		r	DCY04, p333
Production Waste (pick/weft back)	Warp Yarn	(22)	0.4%		r	DCY04, p333
	Weft Yarn	(23)	0.8%		r	DCY04, p333
Loss	Warp Yarn	(24)	3.0%		r,a	DCF13
	Weft Yarn	(25)	3.0%		r,a	DCF13
Yardage Allowance	Warp Yarn	(26)	0.9%		r,a	DCY04, p333
	Weft Yarn	(27)	0.9%		r,a	DCY04, p333
Yarn Usage & Cost						
Warp Yarn (14.5tex)	Fabric Usage	(29)	116.92	g/m	c	=H16*H12*(1+H26)*(1+H24)/(1000*(1-H18)*(1+H20)*(1-H22))
	Usage /Shirt	(30)	140.44	g	c	=H29*H10
	Price	(31)	40,000	￥/t	r,a	DAL05
Weft Yarn (18/2tex)	Fabric Usage	(32)	27.96	g/m	c	=H15*H7*18*2*(1+H27)*(1+H25)/(10*1000*(1-H19)*(1-H23))
	Usage /Shirt	(33)	33.58	g	c	=H32*H10
	Price	(34)	40,000	￥/t	r,a	DAL05
Threads (14.5/2tex)	Usage /Shirt	(35)	130.00	m	e	Table 6.3
	Usage /Shirt	(36)	3.77	g	c	=H35*H12*2/1000
	Price	(37)	50,000	￥/t	r,a	DAL05
Usage%	for Warp Yarn	(38)	78.99%		c	=H30/(H$30+H$33+H$36)
	for Weft Yarn	(39)	18.89%		c	=H33/(H$30+H$33+H$36)
	for Threads	(40)	2.12%		c	=H36/(H$30+H$33+H$36)

Note: r/reference, a/assumption, e/estimated, c/calculated, s/sample data as example; Rate of moisture regain in cotton materials is not counted in any calculation, however the referene data may included this in it's caculation.
Yarn Usage (g/m) = Total No. of Yarn x Yarn Count x (1+ Yardage Allowance) x (1+Loss) / 1000 x [(1-shrinkage) x (1+Stretch) x (1+Production Waste)]

Source: The Author

6.4 Input-Output Production Data

6.4.1 Inputs and Outputs of Cotton Material at Production Phases

The input and output of cotton material at each stage of production can be calculated to organize the production of yarn, fabric, and garments. This is based on the Australian cotton output for 2021, which amounted to 1,277,000 tons of cotton lint. The data required for these calculations is available in Table 6.9. The data source, located in column "H", links to Table 6.1 and 6.2, except for the calculated data, which formulas is provided instead.

Table 6.9: Data Reference and Source Document "AC"

Table: Data Reference and Source Document Code: AC			Version: V1		Date: 10/08/2024
Reference Data			Data Applied		Reference Data Source/Formula
Type	Code	Description	Number	Measure	
		E	F	G	H
Australian Cotton Planting Area	(7)	635,000 hectare in 2021	635,000	ha	DCF09
Australia Cotton Seeds Packing	(8)	20kg bag, 800kg bag		kg	DCF03
Australia Cotton Seeds Price	(9)	AU $6.7 - 27.2/kg	10.0	/kg AU$	DCF03
Average Cotton Seeds/ha	(10)	13kg	13	kg	DCF01
Seed Cotton Annual Production Volumn in Australia	(11)	3,451,351	3,451,351	ton	=F19/F47
Australia Seed Cotton Packing	(12)	(around) 2.5 ton Module			DCF03
Australia Seed Cotton Price	(13)	cotton farmer is generally paid after cotton ginning			DCF03
Australian Cotton Growing Statistics	(14)	revenue $4.3bn (lint and seed) (Y2021)	4.3	AU$ bn	DAL07
	(15)	profit $918.0m; profit Margin 21.5% (Y2021)			DAL07
	(16)	business 1,096 (Y2021)	1,096		DAL07
	(17)	employment 12,291 (Y2021)	12,291		DAL07
	(18)	wage $354.2m (Y2021)	354.2	AU$ m	DAL07
Cotton Lint Annual Production Volumn in Australia	(19)	1277000 ton (Y2021)	1,277,000	ton	DCF09
	(20)	5625000 bale (Y2021)	5,625,000	bale	DCF09
Australia Cotton Lint Revenue	(21)	$3.4 bn	3.4	AU$ bn	DCF09
Australia Cotton Lint Packing	(22)	227kg/bale			DCF03
Cotton Ginning in Australia Statistics	(23)	revenue $6.3bn (Y2021)	6.3	AU$ bn	DAL07
	(24)	profit $856.3m; profit Margin 13.7% (Y2021)			DAL07
	(25)	business 38 (Y2021)	38		DAL07
	(26)	employment 1,801 (Y2021)	1,801		DAL07
	(27)	wage $131.2m (Y2021)	131.2	AU$ m	DAL07
Cotton Lint Price for Australia Farmer	(28)	(c)AU$604/bale	600.0	AU$/bale	=(F21*1000000000)/F20
Cotton Lint Price for Australia Ginner	(29)	(c)AU$938/bale	945.0	AU$/bale	=(F23-(F14-F21)*(1+13.7%))*1000000000/F20
Cotton Yarn Packing	(30)	e_0.9 - 2.5kg/cone, 24/36/..cone per pack	2	kg/cone	DAL06
Cotton Thread Packing	(31)	e_3000 - 4000yd/cone, 24/36/..cone per pack	4000	yd/cone	DAL05

Australian Cotton Allocated to Yarn	(32)	Wrap Yarn 14.5tex yarn	78.99%		Table 6.8
	(33)	Weft Yarn 18tex/2 yarn	18.89%		Table 6.8
	(34)	14.5tex/2 thread	2.12%		Table 6.8
Cotton Yarn in Australian Cotton Price	(35)	e_￥35,000 - 80,000/ton	40,000	￥/ton	DAL05
	(36)		50,000	￥/ton	DAL05
Fabric Packing	(37)	(around) 10-100 metres/piece	40	m/piece	DAL06
Grey (ACOXF-01) Cotton Oxford Price	(38)	vary	14	￥/m	DAL05
White Cotton Oxford (ACOXF-01) Price	(39)	vary	25	￥/m	DAL05
ACOXF-01 Weight	(40)	145g/m	145	g/m	=Table 6.8_ H(29)+H(32)
Shirt ACSHIRT_01 Fabric Usage	(41)		1.202	m/piece	Table 6.8
Shirt ACSHIRT_01 FOB Price	(42)	vary	12	US$/piece	DAL06
Exchange Rate	(43)	AU$/CN￥	4.7		DAL05
	(44)	US$/AU$	1.5		DAL05
Garment Packing	(45)	1-50 pieces in carton (most common), or pieces on hanger	20	pieces /carton	DAL06
Australian Cotton Shirt Retail Price	(46)	$79.99 - 160 / piece	79.99	AU$/kg	DAL05
Cotton Lint%	(47)	cotton lint 37%	37%		DAL03
Production Loss - seed cotton to cotton lint	(48)	cotton seeds 53%, cotton motes 1.2%, burs 3.1%, leaf and dirt 4.5%, sticks 1.2%	63%		DAL03
Production Loss - cotton lint to yarn	(49)	carded (ring-spun yarn, 14%) , combed (ring-spun yarn, 26%), Open-End (rotor yarn, 10%)	26%		DAL03
Production Loss - yarn to grey fabric	(50)	denim (6%), woven (10%), circular knit (12%), flat knit (13%), home textiles (11%)	10%		DAL03
Production Loss - fabric dyeing, printing, and finishing	(51)	shrinkage of dye - cotton without Stretch (3-5%)	3%		DAL03
Production Loss - fabric to finished textile products	(52)	due to fabric defects, pattern replacement, etc	3%		DAL06
Fabric Waste - textile production	(53)	apparel - knits / wovens (18%), apparel - denim (15%), home textiles (5%)	18%		DAL03
Bulk Garment Loss	(54)	due to garment defects, lost, etc	0.05%		DAL06

Source: The Author

These data enable the calculation of cotton material input and output at various phases: cotton farming, cotton ginning, yarn production, grey fabric (ACOXF-01) production, fabric dyeing, printing, finishing, and garment production. All numerical values are computed using formulas linked to these data and presented in Table 6.10.

Table 6.10: Production Phases & Cotton Material Flow

Table: ACSHIRT_01 Production Phases & Cotton Material Flow										
Document Code: CC						Version: V1			Date: 10/08/2024	
Production Phases /Cotton Material Flow			Code	**Cotton Farming**	**Cotton Ginning**	**Yarn Production**			**Grey Fabric Production**	
				G	H	I	J	K	L	M
Input	Name			cotton seeds	seed cotton	cotton lint			14.5tex yarn	18tex/2 yarn
	Qty (ton)		(7)	8,255	3,451,351	1,277,000			746,440	178,507
	Cost Price		(8)	AU $10/kg	AU $600/bale	AU $945/bale			￥40000/t	
	Cost (AU million$)		(9)	0.08	3,375	5,316			6,353	1,519
	Produciton Loss	%	(10)	na	63%	26%			10%	
		Qty (ton)	(11)	na	2,174,351	332,020			74,644	17,851
Output	Name			seed cotton	cotton lint	14.5tex yarn	18tex/2 yarn	14.5tex/2 thread	14.5 x 18/2 tex cotton oxford	
	Qty		(13)	3,451,351	5,625	746,440	178,507	20,034	5,741,046,770	
	Measure		(14)	ton	000' bale	ton	ton	ton	m	
	Sale Price		(15)	AU $600/bale	AU	￥40000/t		￥50000/t	￥14/m	
	Value (AU million$)		(17)	3,375	5,316	6,353	1,519	213	17,101	
	Packing		(18)	module	bale	36 cone/pack		100 c/pk	40m (pc) x 5/pack	
				Fabric Dyeing, Printing, and Finishing		**Garment Production**				**Retail**
Input	Name			grey cotton oxford		cotton oxford, white		14.5tex/2 thread		Shirt ACSHIRT_01
	Qty		(20)	5,741,046,770		5,568,815,367		186,981,856		4,495,091,042
	Measure		(21)	m		m		cone		pieces
	Cost Price /Measure (AU$)		(22)	2.98		5.32		1.14		18.12
	Cost (AU million$)		(23)	17,101		29,621		213		81,451
	Produciton Loss	%	(24)	3%		3%		deem as thread waste		0.05%
		Qty	(25)	172,231,403		167,064,461				2,247,546
		Msr	(26)	m		m				pieces
Output	Name			cotton oxford, white, 140gsm, 14.5 x 18/2 tex, 120 x 50		Shirt ACSHIRT_01				Shirt ACSHIRT_01
	Qty		(28)	5,568,815,367		4,495,091,042				4,492,843,497
	Measure		(29)	m		pieces				pieces
	Sale Price		(30)	￥25/m		US $12				AU $79.99
	Value (AU million$)		(31)	29,621		81,451				359,383
	Packing		(32)	40m (pc) x 5/pack		20 pieces/box				

The Formulas

Table: ACSHIRT_01 Production Phases & Cotton Material Flow										
Document Code: CC						Version: V1			Date: 45514	
Production Phases /Cotton Material Flow			Code	**Cotton Farming**	**Cotton Ginning**	**Yarn Production**			**Grey Fabric Production**	
				G	H	I	J	K	L	M
Input	Name			cotton seeds	seed cotton	cotton lint			14.5tex yarn	18tex/2 yarn
	Qty (ton)		(7)	=AC!F7*AC!F10/1000	=G12	=AC!F19			=I12	=J12
	Cost Price		(8)	="AU $"&AC!F9&"/kg"	=G14	=H14			=I14	
	Cost (AU million$)		(9)	=G6*AC!F9/1000000	=G15	=H15			=I15	=J15
	Produciton Loss	%	(10)	na	=AC!F48	=AC!F49			=AC!F50	
		Qty (ton)	(11)	na	=H6*H9	=I6*I9			=L6*L9	=M6*L9
Output	Name			seed cotton	cotton lint	14.5tex yarn	18tex/2 yarn	14.5tex/2 thread	14.5 x 18/2 tex cotton oxford	
	Qty		(13)	=AC!F11	=AC!F20/1000	=(I6-I10)*AC!	=(I6-I10)*AC!	=(I6-I10)*AC!F3	=(L6+M6-L10-M10)*1000/(AC!F40/1000)	
	Measure		(14)	ton	000' bale	ton	ton	ton	m	
	Sale Price		(15)	="AU $"&AC!F28&"/bale"	="AU $"&AC!F29&"/bale"	="￥"&AC!F35&"/t"		="￥"&AC!F36&"/t"	="￥"&AC!F38&"/m"	
	Value (AU million$)		(17)	=AC!F20*AC!F28/1000000	=945*H12/1000	=I12*AC!F35/AC!F	=J12*AC!F35/AC!F	=K12*AC!F36/AC!F4	=L12*AC!F38/AC!F43/1000000	
	Packing		(18)	module	bale	36 cone/pack		100 c/pk	40m (pc) x 5/pack	
				Fabric Dyeing, Printing, and Finishing		**Garment Production**				**Retail**
Input	Name			grey cotton oxford		cotton oxford, white		14.5tex/2 thread		Shirt ACSHIRT_01
	Qty		(20)	=L12		=G27		=K12*(1-1%)*1000*1000/(14.5*2/1000*(4000*0		=I27
	Measure		(21)	=L13		=G28		cone		pieces
	Cost Price /Measure (AU$)		(22)	=AC!F38/AC!F43		=AC!F39/AC!F43		=K15*1000000/K19		=AC!F42*AC!F44
	Cost (AU million$)		(23)	=G21*G19/1000000		=I21*I19/1000000		=K21*K19/1000000		=I30
	Produciton Loss	%	(24)	=AC!F51		=AC!F52		deem as thread waste		=AC!F54
		Qty	(25)	=G19*G23		=I19*I23				=M19*M23
		Msr	(26)	m		m				pieces
Output	Name			cotton oxford, white, 140gsm, 14.5 x 18/2 tex, 120 x 50		Shirt ACSHIRT_01				Shirt ACSHIRT_01
	Qty		(28)	=G19-G24		=(I19-I24)/AC!F41				=M19-M24
	Measure		(29)	m		pieces				pieces
	Sale Price		(30)	="￥"&AC!F39&"/m"		="US $"&AC!F42				="AU $"&AC!F46
	Value (AU million$)		(31)	=G27*AC!F39/AC!F43/1000000		=AC!F42*AC!F44*I27/1000000				=AC!F46*M27/1000000
	Packing		(32)	40m (pc) x 5/pack		20 pieces/box				

Source: The Author

Based on the calculations, 8,255 tons of cotton seeds, valued at $0.08 million, yield 3.4 million tons (or 1.4 million modules) of seed cotton, valued at $3.4 billion. These in turn produce 5.6 million bales of cotton lint, valued at $5.3 billion, which are used to produce 0.9 million tons of yarn, valued at $8.0 billion. From this yarn, 5.7 billion meters of grey cotton oxford (ACOXF-01) are produced, valued at $17 billion, leading to the production of 5.6 billion meters of white cotton oxford (ACOXF-01), valued at $3.0 billion. Finally, this results in 4.5 billion casual cotton shirts (ACSHIRT_01), valued at $81 billion, with a retail value of $359 billion.

All the aforementioned dollar values are expressed in Australian currency and assume that the production phases from cotton lint to finished shirt are carried out in China when estimating the dollar value of production.

6.4.2 Production Processes

Production processes are crucial for the design of manufacturing plants and play a determining role in considerations including plant location and infrastructure, machinery, and labour. Chapter 5 meticulously documents the production processes for a standard cotton garment, starting from the seed and encompassing all vital, as well as optional and alternative steps. This section specifically delineates the production chain involving yarn creation, the manufacturing of grey fabric, fabric dyeing and finishing, leading up to the final garment assembly. It focuses on the particular processes that utilize Australian-processed cotton lint in the production of the shirt (code ACSHIRT_01). It is important to note that the flowcharts exclude certain supporting processes. For instance, in the printing process, preparing the print patterns is a necessary step that is not depicted in the flowcharts, similar to other ancillary procedures.

Table 6.11 showcases a list of yarn production processes that convert Australian cotton lint into the specified yarns required for the ACSHIRT_01 shirt. These include the warp yarn with a fineness of 14.5tex, the weft yarn at 18tex/2, and the sewing threads at 14.5tex/2, which are all defined as fine yarn counts. The list provided generally illustrates the order of the processes involved, although it may not represent a precise 100% correct sequence. Additionally, some processes may be rearranged to accommodate the preferences of specific operations. For instance, the yarn twist-fixing step could be executed at either the yarn manufacturing facility prior to packaging or at the fabric manufacturing facility before weaving.

Table 6.11: Shirt ACSSHIRT_01 Yarn Production Processes

Table: Shirt ACSHIRT_01 Yarn Production Processes				
Document Code: DD	Version: V1	Date:	10/08/2024	
Yarn Production Process		14.5tex	18tex/2	14.5tex/2
		warp yarn	weft yarn	sewing threads
	Code	G	H	I
Blowing & Carding (incl. opening, cleaning)	(7)	x	x	x
First Drawing	(8)	x	x	x
Combing	(9)	x	x	x
Second Drawing	(10)	x	x	x
Third Drawing	(11)			
Roving	(12)	x	x	x
Spinning				
Conventional Ring Spinning	(14)	x	x	x
Compact Ring Spinning	(15)			
Siro Ring Spinning	(16)			
Siro Compact Ring Spinning	(17)			
Rotor Spinning	(18)			
Air-jet Spinning	(19)			
Votex Spinning	(20)			
Yarn Doubling	(21)		x	x
Yarn Twisting	(22)		x	x
Yarn Singeing	(23)			x
Yarn Dye				
Bobbin Dye	(25)			x
Hank Dye	(26)			
Yarn Mercerising	(27)			
Winding				
Winding	(29)	x	x	x
Loose Winding	(30)			x
Reeling	(31)			
Prin Winding	(32)			
Twist Fixing				
Natural Twist Stablization	(34)			
Moisture Setting	(35)			
Heat & Moisture Setting	(36)		x	x
Packing	(37)	x	x	x

Source: The Author

Table 6.12 presents a compilation of processes for the production of grey fabric, which converts the previously mentioned warp and weft yarns into the shirt base fabric in oxford structure, a variation of plain weave. Similar to the yarn production list detailed earlier, the outlined process steps generally depict the sequence of operations, although it is important to note that the order may not be exactly 100% accurate.

Table 6.12: Shirt ACSSHIRT_01 Fabric Production Processes

Table: Shirt ACSHIRT_01 Fabric Production Processes				
Document Code: DF	Version: V1		Date:	10/08/2024
Fabric Production Process		Warp yarn	Weft yarn	Grey Fabric
		14.5tex	18tex/2	
	Code	G	H	I
Warpping (incl. creeling)				
Sectional Warpping (Beam Warping) & Sizing	(8)	x		
Sectional Warpping (Beam Warping)	(9)			
Batch Warping	(10)			
Votex Spinning	(11)			
Drawing-in	(12)	x		
Twist Fixing	(13)		(x)	
Winding				
Winding	(15)		(x)	
Prin Winding	(16)			
Weaving				
Shuttleless Weaving	(18)			
Rapier Loom	(19)			
Air-jet Loom	(20)	x	x	
Gripper Loom	(21)			
Water-jet Loom (not for cotton material)	(22)			
Shuttle Weaving	(23)			
Beam Transport				
Warp Beam	(25)	x		
Weaver's Beam	(26)	x		
Fabric Beam	(27)			x
Post Handling (not necessary in sequence)				
Inspection	(29)			x
(Brushing)	(30)			x
(Drying)	(31)			
(Folding, Weighting)	(32)			x
(Mending, Washing)	(33)			x
Grading, Labelling, Sample Inspection, Packing	(34)			x

Source: The Author

Table 6.13 outlines the series of processes for fabric dyeing and finishing, which transform the basic cotton oxford into a finished white fabric (code ACOXF-01) ready for garment production. As previously mentioned, the steps illustrated provide a general overview of the operational sequence. However, it is essential to recognize that the exact order may not be strictly 100% accurate. This flexibility is particularly relevant for processes like mercerising, which may be carried out during the pre-treatment stage, the post-treatment stage, or sometimes partially in the pre-treatment and then repeated in the post-treatment stage, based on the fabric's characteristics and the operator's expertise.

Table 6.13: Shirt ACSHIRT_01 Fabric Dyeing and Finishing Processes

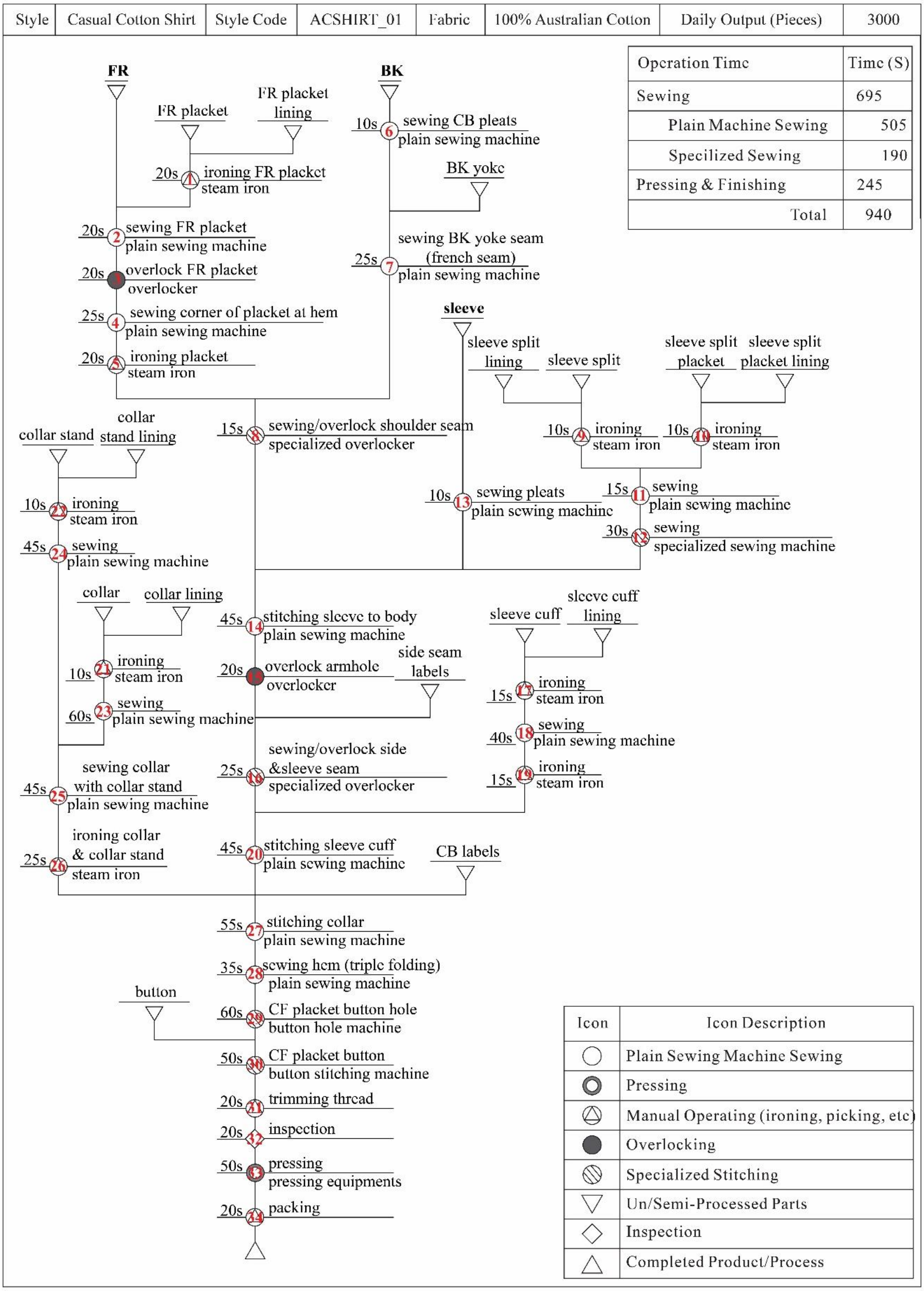
Table: Shirt ACSHIRT_01 Fabric Dyeing and Finishing Processes			
Document Code: DY	Version: V1	Date: 10/08/2024	
Fabric Dyeing, Printing, and Finishing Process		Fabric	Note
	Code	G	H
Grey Fabric Inspection			
Inspection (Woven or Knitted)	(7)	x	
Opening & Inspection (Knitted Fabric)	(8)		
Pre-treatment			
Pieces Matching	(10)	x	
Pieces Stitching (Connecting)	(11)	x	
Singeing	(12)	x	
For Woven Fabric			
Desizing, Scouring, Bleaching	(14)		
Desizing, Scouring, Bleaching, and Whitening	(15)	x	
For Knitted Fabric			
Scouring, Bleaching, and Softening	(17)		
Scouring, Bleaching, Softening, and Whitening	(18)		
Scouring, Bleaching, Dyeing, and Softening	(19)		
Dehydration	(20)		
Drying	(21)	x	
Mercerizing	(22)	x	
Dyeing			
Dyeing Methods			
Pad Dyeing	(25)		
Jigger Dyeing	(26)		
Winch Dyeing	(27)		
Drying	(28)		
Printing			
Printing Methods			
Roller Printing	(31)		
Flat Screen Printing	(32)		
Rotary Screen Printing	(33)		
Transfer Printing	(34)		
Inkjet (Digital) Printing	(35)		
Colour Fixing	(36)		
Soaping	(37)		
Washing	(38)		
Finishing			
Post Finishing			
Heat Setting	(41)		
Stentering	(42)	x	
Sanforizing	(43)	x	
Calendering	(44)		
Pile Finishing	(45)		
Hand Feeling Finishing	(46)	x	
Resin Finishing	(47)		
Mercerizing	(48)		
Liquid Ammonia Treatment (high end fabric)	(49)		
Functional Finishing			
Easy-care treatments	(51)	x	
Water- and oil-repellent treatments	(52)		
Flame-retardant treatments	(53)		
Anti-static treatments	(54)		
Mothproofing treatments	(55)		
Bactericidal and fungicidal treatments	(56)		
Unti-UV Treatment	(57)		
Post Handling			
Finished Fabric Inspection			
Inspection (Woven or Knitted)	(60)		
Opening & Inspection (Knitted Fabric)	(61)		
Drying	(62)		
Folding	(63)	x	
Weighting	(64)	x	
Grading	(65)	x	
Sample Inspection	(66)	x	
Packing	(67)	x	

Source: The Author

Garment production is, however, more labour-intensive compared to the yarn, fabric production, and processes of dyeing, printing, and finishing, which are predominantly machine-driven in modern industrial settings. A superficial assessment indicates that garment production can significantly differ from one style to another, between factories, and even among workers. Fundamentally, the variability encountered in producing a singular style can appear to be quite daunting. Yet, it is surmised that there exist fundamental principles that govern the garment production process, which necessitate further empirical research to develop a conceptual framework. The processes detailed here outline the general workflow for crafting a shirt once its design, pattern, and materials have been finalized. From this point, the subsequent operations can be categorized into four main stages: production planning, cutting, sewing, and finishing.

Production planning falls within the domain of entrepreneurial activity and is set for further investigation. Production planning is embraced within the sphere of entrepreneurial tasks and is designated for thorough exploration. During the production planning phase, a variety of documents are created to steer the cutting, sewing, and finishing operations. These documents include shirt production specifications, material records, sewing line arrangements, schedules for bulk cutting, production line calendars, production progress reports, manufacturing statistics, and inspection logs. The specific names and detailed contents of these documents can vary between factories. Figure 6.4 depicts the configurations of the shirt sewing line, outlining the planned distribution of labour and machinery as well as the anticipated standard sewing times, to demonstrate the complexity of garment production.

Figure 6.2: ACSHIRT_01 Sewing Line Allocation



Source: The Author

The cutting and other processes that contribute to the additional documents are simpler yet similar to the sewing line arrangement and therefore are not presented.

6.4.3 Production Facilities and Aggregated Production Data

The hypothesis for producing a shirt from Australian cotton requires assuming facilities capable of achieving the calculated outputs at each stage of production. These facilities, in turn, provide the production data presented in the Input-Output Production Tables.

Australian Cotton Farm

Cotton cultivation occurs in actual Australian facilities. In the absence of real data from these farms, a fictitious entity named "A Farm" is used for production analysis. This hypothetical farm mirrors the average cotton farm in Australia, as characterized by Cotton Australia. It spans 576 hectares dedicated to cotton, which accounts for 10% of its total land area, and it employs nine individuals directly. Based on the 2021 figures from the NSW Department of Primary Industries, the total cotton farmland in Australia covered 635,000 hectares, suggesting the existence of 1,102 farms comparable to "A Farm". Once production data for "A Farm" becomes available, multiplying this data by 1,102 will provide an estimate of the total input and output of cotton farming in Australia. This principle is also applicable to estimating production data for other facilities such as ginning, yarn production, grey fabric production, fabric dyeing, printing, finishing, and garment production, with particular adaptations specified in each section.

The production data in the "A Farm" Input-Output Production Table originates from Table 6.14, detailed below, the data source, found in column “I”, references Table 6.1, except for the calculated data, for which the formulas are provided instead.

Table 6.14: Data Reference and Source Document “AF”

Table: Data Reference and Source Document Code: AF				Version: V1		Date: 10/08/2024
Reference Data				Data Applied		Reference Data Source/Formula
Type		Code	Description	Number	Measure	
			F	G	H	I
Australian Cotton Planting Area		(7)	635,000 hectare in 2021	635,000	ha	DCF09
Average Farm Land Area in Australia		(8)	576 ha	576	ha	DCF03
Number of Cotton Farms		(9)	1102	1,102		=F7/F8
Seed Cotton Annual Production Volumn in Australia		(10)	3,451,351 ton	3,451,351	ton	Table 6.10
Australian Cotton Lint Production Volumn		(11)	5625000 bale (Y2021)	5,625,000	bale	Table 6.10
Australian Cotton Seed Production Value		(12)	0.9 billion	0.9	billion	Table 6.10 =F(14)-F(21)
Cotton Lint Price for Australia Farmer		(13)	(c)AU$604/bale	600	AU$/bale	Table 6.10
NSW Average Farm Land Price		(14)	$9429/ha	9,429	/ha AU$	DCF09
Cotton Farm Water Consumption		(15)	9ML/ha	9	/ha	DCF01
Irrigate Water Price		(16)	$61.5/ML	62	/ML	DCF01
Fossil Fuels Consumption		(17)	(e, c) 250L/ha	220	L/ha	DCF01
Fossil Fuels Price		(18)	$1.2/L	1.20	/L AU$	DCF01
Average Cotton Seeds/ha		(19)	13kg/ha	13	kg/ha	DCF01
Australia Cotton Seeds Price		(20)	AU $6.7 - 27.2/kg	10.0	/kg AU$	DCF01
Cotton Farming - Fertiliser	Consumption	(21)	691kg/ha	691	kg/ha	DCF01
	Cost	(22)	$1.12/kg	1.12	/kg AU$	DCF01
Cotton Farming - Herbicide	Consumption	(23)	8.16kg/ha	8.16	kg/ha	DCF01
	Cost	(24)	$62.7/kg	16.00	/kg AU$	DCF01
Cotton Farming - Growth Regulant	Consumption	(25)	98.8g/ha	98.8	g/ha	DCF01
	Cost	(26)	$16/kg	62.7	/kg AU$	DCF01
Cotton Farming - Insecticide	Consumption	(27)	245g/ha	245	g/ha	DCF01
	Cost	(28)	$613.8/kg	614	/kg AU$	DCF01
Cotton Farming - Defolication	Consumption	(29)	2.35kg/ha	2.35	kg/ha	DCF01
	Cost	(30)	$43.3/kg	43.3	/kg AU$	DCF01
Cost - Cotton Farming Primary Machinery (incl. Processing Material)	fertiliser drilled; fertiliser spread; fertiliser side-dress aerial spraying; shielded sprayer; self-propelled sprayer	(31)	contract $1000/ha ex labour or own	1000	/ha AU$	DCF03
Average Labour per Cotton Farm	Primary Skilled Labour: cotton technician; irrigation technician; machinery operator	(32)	"directly creates jobs for nine people"	3		"DCF03" Author justified the allocation of labour
	general labourer	(33)		6		
Cost - Labour	Primary Skilled Labour: cotton technician; irrigation technician; machinery operator	(34)	$180,000 / Labour /Annual	180,000	/Annual AU$	Author justified the cost of labour
	general labourer	(35)	$100,000 / Labour /Annual	100,000	/Annual AU$	

Source: The Author

The production data for "A Farm" is calculated using formulas associated with these data, as presented in Table 6.14.

Table 6.15: “A Farm” Production Input-Output Table

Table: “A Farm” Input-Output Production Table									
	Document Code	DF				Version:	V1	Date:	10/08/2024
Description		Code	Item	Quantity		$Value/Cost (AU)		Key Contri Process	**Note**
				Number	Measure	Number	Measure		
			G	H	I	J	K		
Business	Production Capacity	(7)							
Input	**Land**								
	Land	(9)	farm land	576	ha	5.43	million		asset
	Water	(10)		5,184	ML	0.32	million	Growing	
	Electricity	(11)	NA						
	Fossil Fuels	(12)		126,720	L	0.15	million		
	Gas	(13)	NA						
	Material								
	Primary Material	(15)	cotton seeds	7,488	kg	0.07	million		
	<u>Auxiliary Material</u>	(16)	fertiliser; herbicide; growth regulant; insecticide; defolication	404,268	kg	0.67	million	Growing	
	Machinery								
	Primary Machinery (incl. Processing Material)	(18)	fertiliser drilled; fertiliser spread; fertiliser side-dress aerial spraying; shielded sprayer; self-propelled sprayer	contract		0.58	million	Growing	
	Parts/Components	(19)	NA						
	Labour								
	Primary Skilled Labour	(21)	cotton technician; irrigation technician; machinery operator	3		0.54	million		
	Supporting Labour	(22)	general labour	6		0.60	million		
	Overheads (incl. Management)	(23)	farmer/owner						
	Entrepreneuship		for future investigation at the intended PhD stage						
Output	**Economic**								
	Annual Output	(26)	seed cotton	3,132	ton	3.06	million		
	By-product	(27)	cotton seeds (own)			0.82	million		
	Environmental								
	Gegeral Solid Waste	(29)	LM						
	Hazardous Solid Waste	(30)	NS						
	Waste Water	(31)	LM						
	Air Pollutant	(32)	NS					growing	
	Social		for future investigation at the intended PhD stage						
Note	NS/not significant; LM/too limited to count; NA/not available								

Source: The Author

The formulas used in Table 6.15 are detailed in Table 6.16, below.

Table 6.16: Formulas for Table 6.15	
H column	J column
H(9)=AF!G8	J(9)=H8*AF!G14/1000000

H(10)=H8*AF!G15 H(12)=H8*AF!G17 H(15)=H8*AF!G19 H(16)=H8*(AF!G21+AF!G23+AF!G25/1000+AF!G27/1000+AF!G29) H(21)=AF!G32 H(22)=AF!G33 H(26)=AF!G10/AF!G9	J(10)=H9*AF!G16/1000000 J(12)=H11*AF!G18/1000000 J(15)=H14*AF!G20/1000000 J(16)=H8*(SUM(AF!G21*AF!G22+AF!G23*AF!G24+(AF!G25*AF!G26/1000)+(AF!G27*AF!G28/1000)+AF!G29*AF!G30)/1000000) J(18)=H8*AF!G31/1000000 J(21)=H20*AF!G34/1000000 J(22)=H21*AF!G35/1000000 J(26)=AF!G11/AF!G9*AF!G13/1000000 J(27)=AF!G12*1000/AF!G9

Australian Cotton Gin

Based on a real Australian gin facility visited by the author, which features six gin stands and a daily output of 800-1000 cotton lint bales operating 24 hours a day with 17 direct production workers during the day shift and 15 at night, the hypothetical "B Gin" facility is modelled. In Australia, full-time employees work 2,080 hours annually. It is projected that "B Gin" operates 2,088 hours across 87 days, each day around the clock, with all workers classified as full-time. With an assumed daily output of 1,000 bales, the annual production of "B Gin" is estimated at 87,000 bales. To process the total Australian seed cotton, 65 such "B Gin" facilities would be required. Once production data for "B Gin" becomes available, multiplying this data by 65 will provide an estimate of the total input and output of cotton ginning in Australia. While there are approximately 40 cotton gin facilities in Australia, it's noteworthy that the daily output data collected by the author significantly underestimates the capacity described in the North Queensland Cotton Gin Assessment and Feasibility Study. This study indicates that a three-stand cotton gin can process 60 bales per hour, equating to 1,440 bales per day (Leith 2021).

The production data in the "B Gin" Input-Output Production Table originates from Table 6.17, detailed below, the data source, found in column “M”, references Table 6.1, except for the calculated data, for which the formulas are provided instead.

Table 17: Data Reference and Source Document “AG”

Table: Data Reference and Source for B Gin										
	Document Code: AG					Version: V1				10/08/2024
Reference Data				Data Applied						Reference Data Source/Formula
				Consum(c)/Product(p)		c/p	Cost(c)/Income(i)		c/i	
Type			Description	Number	Measure		Number	Measure		
		Code	F	G	H		J	K		M
B Gin	Gin Stands	(8)	a system from material feed to output	6						DCG02
	Daily Outputs		800-1000 bales	1,000	bales	p				DCG02
	Operation Days		per year	87	days					author justified
	Operation Hours		per day	24	hours					DCG02
	Operation Hours		per year	2,088	/year					=G9*G10
	Primary Skilled Labour	()	17 direct production workers during the day shift and 15 at night	20			90,000	per labour per annual	c	author justified the allocation and cost of labour
	Supporting Labour	()		11			70,000		c	
	Overheads (Incl. Management)	()		2			100,000		c	
Australia	Seed Cotton	()	annual input	3,451,351	ton	c				
	Cotton Lint	()	annual output	1,277,000	ton	p	945	/bale AU$	i	DCF09
				5,625,000	bales	p	600	/bale AU$	c	DCF09
	Cotton Seed		annual output, farmer own	1,829,216	ton		0.9	million		=G16*G28
			ginner charge handling fee (ginner profit margin)	13.7%					i	DAL07
	Average Farm Land Price		NSW				9,429	/ha AU$		DCF09
	Gin Area		"Land area of approximately 80 to 100 hectares"	100	ha					North Queensland Cotton Gin Assessment and Feasibility Study
	Average (Electricity Use Per Bale		the average (electricity use per bale) being 52.3 kWh (188.3 MJ).	52.3	KWh	c	0.15	/KWh AU$	c	DCG01
	Weight of Cotton Bale		227 kg per bale	227	kg/bale					DCF03
	Number of Gin Facilities		Actural around 40	40						DAL07
			Calculated B Gin	65						=G14/G13
General	Cotton Lint in Seed Cotton		cotton lint 37%	37%						DCG03
	Cotton Seeds in Seed Cotton	(28)	cotton seeds 53%	53%						DCG03
	Cotton Trash in Seed Cotton	(30)	cotton motes 1.2%, burs 3.1%, leaf and dirt 4.5%, sticks 1.2%	10%	ton					DCG03
	Total PM		Total PM of NO.2c	1.4	kg/bale					DCG03 (justified from it's Table 4-3)

Source: The Author

The production data for "B Gin" is calculated using formulas associated with these data, as presented in Table 6.18.

Table 6.18: “B Gin” Production Input-Output Table

Table: "B Gin" Input-Output Production Table
Document Code: GB Version: V1 Date: 10/08/2024

Description		Code	Item	Quantity Number	Quantity Measure	$Value/Cost (AU) Number	$Value/Cost (AU) Measure	Key Contri Process	Note
			G	H	I	J	K		
Business	Production Capacity	(7)	bales per day	>1500	bale				author justified
Input	**Land**								
	Land	(9)	factory and yard	100	ha	0.94	million		
	Water	(10)	NA						
	Electricity	(11)		4,550,100	KWh	0.68	million		
	Fossil Fuels	(12)	NA						
	Gas	(13)	NA						
	Material								
	Primary Material	(15)	seed cotton	53,098	ton	51.92	million		
	Auxiliary Material	(16)	NA						
	Machinery								
	Primary Machinery (Processing Material)	(18)	gin stands (system)	6		>20	million		author justified
	Parts/Components	(19)	NA						
	Labour								
	Primary Skilled Labour	(21)		20		90,000	million		
	Supporting Labour	(22)		11		70,000	million		
	Overheads (incl. Management)	(23)		2		100,000	million		
	Entrepreneuship		for future investigation at the intended PhD stage						
Output	**Economic**								
	Annual Output	(26)	cotton lint	87,000	bale	0.00	million		
	By-product	(27)	cotton seeds (handling)	10,467	ton	0.01	million		
	Environmental								
	Gegeral Solid Waste	(29)	trash	5,310	ton				
	Hazardous Solid Waste	(30)	NS						
	Waste Water	(31)	NS						
	Air Pollutant	(32)	PM	121.8	ton				
	Social		for future investigation at the intended PhD stage						
Note	NS/not significant; LM/too limited to count; NA/not available								

Table: "B Gin" Input-Output Production Table
Document Code: GB Version: V1 Date: 45514

Description		Code	Item	Quantity Number	Quantity Measure	$Value/Cost (AU) Number	$Value/Cost (AU) Measure	Key Contri	Note
			G	H	I	J	K		
Business	Production Capacity	(7)	bales per day	>1500	bale				author justified
Input	**Land**								
	Land	(9)	factory and yard	=AG!G22	ha	=G9*AG!J21/1000000	million		
	Water	(10)	NA						
	Electricity	(11)		=AG!G9*AG!G10*AG!G23	KWh	=G11*AG!J23/1000000	million		
	Fossil Fuels	(12)	NA						
	Gas	(13)	NA						
	Material								
	Primary Material	(15)	seed cotton	=AG!G16/AG!G26	ton	=AG!G18/AG!G26*AG!J18/1000000	million		
	Auxiliary Material	(16)	NA						
	Machinery								
	Primary Machinery (Processing Material)	(18)	gin stands (system)	=AG!G8		>20	million		author justified
	Parts/Components	(19)	NA						
	Labour								
	rimary Skilled Labo	(21)		=AG!G13		=AG!J13	million		
	Supporting Labour	(22)		=AG!G14		=AG!J14	million		
	Overheads (incl. Management)	(23)		=AG!G15		=AG!J15	million		
	Entrepreneuship		for future investigation at the intended PhD stage						
Output	**Economic**								
	Annual Output	(26)	cotton lint	=AG!G10*AG!G9	bale	=G26*AG!J16/1000000	million		
	By-product	(27)	cotton seeds (handling)	=G26*AG!G28*AG!G24/1000	ton	=AG!J19/AG!G26	million		
	Environmental								
	Gegeral Solid Wast	(29)	trash	=G15*AG!G29	ton				
	azardous Solid Was	(30)	NS						
	Waste Water	(31)	NS						
	Air Pollutant	(32)	PM	=G26*AG!G30/1000	ton				
	Social		for future investigation at the intended PhD stage						
Note	NS/not significant; LM/too limited to count; NA/not available								

Formula as left

Source: The Author

Cotton Yarn Production Factory

Ninety-nine percent of Australian cotton lint is exported, primarily to Asia, due to the lack of local yarn production facilities. Recently, efforts have been made to establish domestic yarn production facilities. For analytical purposes, it is necessary to assume the existence of a hypothetical yarn production facility in China called "C Yarn". This facility, equipped with 50,000 cops (a type of cone) spinning machines, has an annual yarn output of 5,000 tons. To process all of Australia's cotton lint, 189 "C Yarn" mills would be required. Therefore, the total impact on Australian cotton yarn production can be estimated by multiplying the output of "C Yarn" by 189.

Table 6.19 presents “C Yarn” key input-output production data.

Table 6.19: “C Yarn” Production Input-Output Table

Table: "C Yarn" Production Input-Output Table

Document Code: CY — Version: V1 — Date: 10/08/2024

Description			Item	Quantity		$Value/Cost (AU)		Key Contri Process	**Data Type (r,a,e,c,s)* /Formula**	
				Number	Measure	Number	Measure			
		Code	G	H	I	J	K			
Business	Production Capacity	(7)	Cotton Yarn	50,000	cop			spinning	r	daily OP
		(8)		5,000	ton				r	per annual
Input	**Land**									
	Land	(10)	factory area	22,163	m²	1.66	million		r,a	rent $75/m²
	Water	(11)		5,000	ML	0.004	million		r,a	1ML/ton
	Electricity	(12)		16,500,000	kWh	0.21	million		r	3.3 kWh/kg
	Fossil Fuels	(13)	NS							
	Gas	(14)	NA							
	Material									
	Primary Material	(16)	cotton lint	6,757	ton	28	million		c	
	Auxiliary Material	(17)								
	Machinery									
	Primary Machinery (Processing Material)	(19)	Vary			>20	million		e	
	Parts/Components	(20)	NA							
	Labour									
	Primary Skilled Labour	(22)	Vary	27		0.47	million		e	
	Supporting Labour	(23)	Vary	156		1.93	million		e	
	Overheads (incl. Management)	(24)	Vary	27		0.82	million		e	
	Entrepreneuship		for future investigation at the intended PhD stage							
Output	**Economic**									
	Annual Output	(27)	14.5tex yarn	3,959	ton	36.81	million		r	
		(28)	18tex/2 yarn	947	ton	8.80	million		r	
		(29)	14.5tex/2 thread	95	ton	0.98	million		r	
	By-product	(30)								
	Environmental									
	Gegeral Solid Waste	(32)	trash (26%)	1,757	ton				r,c	
	Hazardous Solid Waste	(33)	NS							
	Waste Water	(34)	NS							
	Air Pollutant	(35)	PM							
	Social		for future investigation at the intended PhD stage							
Note	r/reference, a/assumption, e/estimated, c/calculated, s/sample data as example; NS/not significant; LM/too limited to count; NA/not available									

Source: The Author

Grey Fabric Production Factory

For this analysis, it is assumed that the "D Fabric" mill has an annual output of 15,000 km of grey cotton oxford fabric. To process all of Australia's cotton yarn, 384 such mills would be needed. Therefore, the total impact on Australian cotton grey fabric production can be estimated by multiplying the output of one "D Fabric" mill by 384.

Table 6.20 presents “D Fabric” key input-output production data.

Table 6.20: “D Fabric” Production Input-Output Table

Table: "D Fabric" Production Input-Output Table										
Document Code: DGF						Version:	V1	Date:	10/08/2024	
Description			Item	Quantity		$Value/Cost (AU)		Key	**Data Type**	
				Number	Measure	Number	Measure	Contri	**(r,a,e,c,s)***	
		Code	G	H	I	J	K	Process	**/Formula**	
Business	Production Capacity	(7)	Grey Cotton Oxford	15,000	km			weaving	r	per annual
		(8)	equip 200 Air-jet loom	2,175	ton				r	per annual
Input	**Land**									
	Land	(10)	factory area	9,960	m²	0.75	million		r,a	rent $75/m²
	Water	(11)			ML		million			1ML/ton
	Electricity	(12)		4,350,000	kWh	0.05	million		r,a	2 kWh/kg
	Fossil Fuels	(13)	NS							
	Gas	(14)	NA							
	Material									
	Primary Material	(16)	14.5tex yarn	1,950	ton	18.13	million		c	
		(17)	18tex/2 yarn	466	ton	4.34	million			
	Auxiliary Material	(18)								
	Machinery									
	Primary Machinery (Processing Material)	(20)	Vary			>20	million		e	
	Parts/Components	(21)	NA							
	Labour									
	Primary Skilled Labour	(23)	Vary	35		0.61	million		e	
	Supporting Labour	(24)	Vary	155		1.92	million		e	
	Overheads (incl. Management)	(25)	Vary	29		0.85	million		e	
	Entrepreneuship		for future investigation at the intended PhD stage							
Output	**Economic**									
	Annual Output	(28)	Cotton Oxford	15,000	km	37.19	million		r	
		(29)		2,175	ton		million			
		(30)				-	million			
	By-product	(31)								
	Environmental									
	Gegeral Solid Waste	(33)	trash (10%)	566	ton				r,c	
	Hazardous Solid Waste	(34)	NS							
	Waste Water	(35)	NS							
	Air Pollutant	(36)	PM							
	Social		for future investigation at the intended PhD stage							
Note	r/reference, a/assumption, e/estimated, c/calculated, s/sample data as example; NS/not significant; LM/too limited to count; NA/not available									

Source: The Author

Fabric Dyeing, Printing, and Finishing Factory

"E Fabric" mill, feature 30,000 km grey cotton oxford bleaching to white colour is assumed for the analysis. To process all of Australia's cotton grey fabric, 186 "E Fabric" mills would be required. Therefore, the total impact on Australian cotton dyeing, printing, and finishing can be estimated by multiplying the output of "E Fabric" by 186.

Table 6.21 presents “E Fabric” key input-output production data.

Table 6.21: “E Fabric” Production Input-Output Table

Table: "E Fabric" Production Input-Output Table										
Document Code: EF					Version:	V1	Date:		10/08/2024	
Description			Item	Quantity		$Value/Cost (AU)		Key	**Data Type**	
				Number	Measure	Number	Measure	Contri	**(r,a,e,c,s)***	
		Code	G	H	I	J	K	Process	**/Formula**	
Business	Production Capacity	(7)	Finished Fabric	30,000	km				r	per annual
		(8)		4,350	ton				r	per annual
Input	**Land**									
	Land	(10)	factory area	20,000	m²	1.50	million		r,a	rent $75/m²
	Water	(11)		300,000	ML	0.25	million			20-27L/m
	Electricity	(12)		1,392,000	kWh	0.02	million		r,a	0.79-1.05 kWh/kg
	Fossil Fuels	(13)								
	Gas	(14)		182	ML	0.11	million			160-180ton steam/km fabric 76L³gas/1ton steam, ￥3/L gas
	Material									
	Primary Material	(16)	Grey Cotton Oxford	30,928	km	83.07	million		c	
	Auxiliary Material	(17)	Chemical Stuff	600,000	kg	1.24	million			1.8-2.2kg/100m
		(18)	Dye Stuff		kg					0.45-0.6kg/100m
	Machinery									
	Primary Machinery (Processing Material)	(20)	Vary			>50	million		e	
	Parts/Components	(21)	NA							
	Labour									
	Primary Skilled Labour	(23)	Vary	55		0.95	million		e	
	Supporting Labour	(24)	Vary	275		3.41	million		e	
	Overheads (incl. Management)	(25)	Vary	50		1.47	million		e	
	Entrepreneuship		for future investigation at the intended PhD stage							
Output	**Economic**									
	Annual Output	(28)	White Cotton Oxford	30,000	km	123.97	million		r	
		(29)		4,350	ton		million			
		(30)					million			
	By-product	(31)								
	Environmental									
	Gegeral Solid Waste	(33)	trash (3%)	131	ton				r,c	
	Hazardous Solid Waste	(34)	NS							
	Waste Water	(35)								
	Air Pollutant	(36)	SO2, VOC							
	Social		for future investigation at the intended PhD stage							
Note	r/reference, a/assumption, e/estimated, c/calculated, s/sample data as example; NS/not significant; LM/too limited to count; NA/not available									

Source: The Author

Cotton Shirt Production Factory

"F Shirt" manufacturer, featuring daily output of 1490802 pieces and annual output of 38,761,412 pieces shirts. To process all of Australia's cotton grey fabric, 120 "F Shirt" mills would be required. Therefore, the total impact on Australian cotton dyeing, printing, and finishing can be estimated by multiplying the output of "F Shirt" by 120.

Table 6.22 presents "F Shirt" key input-output production data.

Table 6.22: "F Shirt" Production Input-Output Table

Table: "F Shirt" Production Input-Output Table										
	Document Code: FG					Version:	V1	Date:		10/08/2024
Description			Item	Quantity		$Value/Cost (AU)		Key Contri Process	**Data Type (r,a,e,c,s)* /Formula**	
				Number	Measure	Number	Measure			
		Code	G	H	I	J	K			
Business	Production Capacity	(7)	Shirts	1,761,882	pieces				r	per annual
		(8)		149,082	pieces					per month
Input	**Land**									
	Land	(10)	factory area	13,000	m²	0.98	million		e	
	Water	(11)			ML	0.00	million			
	Electricity	(12)		42,980	kWh	0.00	million			0.065-0.195 kWh/kg
	Fossil Fuels	(13)								
	Gas	(14)			ML		million			
	Material									
	Primary Material	(16)	Cotton Oxford Fabric	2,117	km	8.75	million		c	
	Auxiliary Material	(17)	Cotton Threads	7	kg	0.07	million		c	
		(18)			kg					
	Machinery									
	Primary Machinery (Processing Material)	(20)	Vary			>15	million		e	
	Parts/Components	(21)	NA							
	Labour									
	Primary Skilled Labour	(23)	Vary	247		4.29	million		e	
	Supporting Labour	(24)	Vary	67		0.83	million		e	
	Overheads (incl. Management)	(25)	Vary	47		1.40	million		e	
	Entrepreneuship		for future investigation at the intended PhD stage							
Output	**Economic**									
	Annual Output	(28)	White Cotton Oxford	1,761,882	pieces	29.95	million		r	
		(29)					million			
		(30)					million			
	By-product	(31)								
	Environmental									
	Gegeral Solid Waste	(33)	trash (17.4%)	368	ton				r,c	
	Hazardous Solid Waste	(34)	NS							
	Waste Water	(35)	NS							
	Air Pollutant	(36)	NS							
	Social		for future investigation at the intended PhD stage							
Note	r/reference, a/assumption, e/estimated, c/calculated, s/sample data as example; NS/not significant; LM/too limited to count; NA/not available									

Source: The Author

6.5 Production Analysis

6.5.1 Economic Measures and Impact Analysis

The production data previously presented can be used to construct economic measures, as detailed in Table 6.23.

Table 6.23: Australian Cotton Global Production Impact _ Economic Measures

Table: Australian Cotton Global Impact - Environmental Measures																
Document Code: AUCIEnM													Version:	V1	Date	10/08/2024
Category				Remarks	Cotton Farming		Cotton Ginning		Yarn Production		Grey Fabric Production		Dyeing, Printing, Finishing		Shirt Production	
					Number	Measure	Number	Measure	Number	Measure	Number	Measure	Number	Measure	Number	Measure
Sustainable Development Goal (UN SDG12 Alignment)		Item	Code	G	H	I	J	K	L	M	N	O	P	Q	R	S
SPG I	Efficient Use of Natural Resources	Land	(7)		635	000 ha	6.5	000 ha	4,189	000 m^2	3,825	000 m^2	3,720	000 m^2	34,268	000 m^2
		Water	(8)		5,713	000 ML			945	000 ML			55,800	000 ML		
		Electricity	(9)				295,757	000 KWh	3,118,500	000 KWh	1,670,400	000 KWh	258,912	000 KWh	113,295	000 KWh
		Fossil Fuels	(10)		159	000 ML										
		Gas	(11)										34	000 ML		
SPG II	Responsible Management of Chemicals	Chemical 1	(12)	fertiliser	439	000 ton	Nap		Nap		Nap		Nap		Nap	
		Chemical 2	(13)	herbicide, insecticide, growth regulant	5.4	000 ton	Nap		Nap		Nap		Nap		Nap	
		Chemical 3	(14)	dye stuff	Nap		Nap		Nav		Nav		Nav		Nav	
		Chemical 4	(15)	chemical stuff	Nav		Nav		Nav		Nav		112	000 ton	Nav	
		Chemical 5	(16)													
		Other	(17)													
SPG III	Responsible Managing and Reducing Waste Generation	**Waste Water**														
		Total Volumn	(19)								1.20	000 ML	43	000 ML		
		COD	(20)								9.37	000 ton	395	000 ton		
		BOD	(21)													
		NH3-N	(22)								0.03	000 ton	0.44	000 ton		
		TN	(23)								0.04	000 ton	3.85	000 ton		
		TP	(24)								0.01	000 ton	1.00	000 ton		
		Air Pollutant														
		Total Volumn	(26)										138	000 ML		
		PM	(27)				500.5	ton					0.86	000 ton		
		Cox	(28)													
		SOx	(29)													
		Nox	(30)													
		TVOC	(31)													
		Solid Waste														
		Cotton Solid Waste	(33)				345	000 ton	332	000 ton	217	000 ton	24.37	000 ton	970	000 ton
		Other Solid Waste	(34)								98	000 ton	279.10	000 ton	4.50	000 ton
		Hazardous Waste	(35)								0.21	ton	5,254	ton	0.09	ton
			Note:	Nap: Not Applicable; Aav: Not Available												

Source: The Author

The impact of Australian cotton on the global economy includes the production of over 4.5 billion shirts, the support of more than 1 million jobs, and the generation of over 75 billion Australian dollars in value from seed to garment manufacturing, culminating in a retail value of 360 billion dollars. However, a definitive analysis of its economic impact is currently unfeasible due to the significant amount of data still unavailable for meaningful analysis.

6.5.2 Environment Measures and Impact Analysis

Currently, there is a lack of comprehensive data within the environmental measure framework, and no comparative data is available to evaluate its opportunities. However, existing data, as detailed in Table 6.24, shed light on significant barriers to establishing a complete cotton supply chain in Australia.

Table 6.24: Australian Cotton Global Production Impact _ Environmental Measures

Table: Australian Cotton Global Production Impact - Environmental Measures															
Document Code: AUCIEnM												Version:	V1	Date	10/08/2024
Category				Remarks	Cotton Farming		Cotton Ginning		Yarn Production		Grey Fabric Production		Dyeing, Printing, Finishing		Shirt Production
					Number	Measure	Number	Measure	Number	Measure	Number	Measure	Number	Measure	Number	Measure
Sustainable Development Goal (UN SDG12 Alignment)		Item	Code	G	H	I	J	K	L	M	N	O	P	Q	R	S
SPG I	Efficient Use of Natural Resources	Land	(7)		635	000 ha	6.5	000 ha	4,189	000 m²	3,825	000 m²	3,720	000 m²	34,268	000 m²
		Water	(8)		5,713	000 ML			945	000 ML			55,800	000 ML		
		Electricity	(9)				295,757	000 KWh	3,118,500	000 KWh	1,670,400	000 KWh	258,912	000 KWh	113,295	000 KWh
		Fossil Fuels	(10)		159	000 ML										
		Gas	(11)										34	000 ML		
SPG II	Responsible Management of Chemicals	Chemical 1	(12)	fertiliser	439	000 ton	Nap		Nap		Nap		Nap		Nap	
		Chemical 2	(13)	herbicide, insecticide, growth regulant	5.4	000 ton	Nap		Nap		Nap		Nap		Nap	
		Chemical 3	(14)	dye stuff	Nap		Nap		Nav		Nav		Nav		Nav	
		Chemical 4	(15)	chemical stuff	Nav		Nav		Nav		Nav		112	000 ton	Nav	
		Chemical 5	(16)													
		Other	(17)													
SPG III	Responsible Managing and Reducing Waste Generation	**Waste Water**														
		Total Volumn	(19)								1.20	000 ML	43	000 ML		
		COD	(20)								9.37	000 ton	395	000 ton		
		BOD	(21)													
		NH3-N	(22)								0.03	000 ton	0.44	000 ton		
		TN	(23)								0.04	000 ton	3.85	000 ton		
		TP	(24)								0.01	000 ton	1.00	000 ton		
		Air Pollutant														
		Total Volumn	(26)										138	000 ML		
		PM	(27)				500.5	ton					0.86	000 ton		
		Cox	(28)													
		SOx	(29)													
		Nox	(30)													
		TVOC	(31)													
		Solid Waste														
		Cotton Solid Waste	(33)				345	000 ton	332	000 ton	217	000 ton	24.37	000 ton	970	000 ton
		Other Solid Waste	(34)								98	000 ton	279.10	000 ton	4.50	000 ton
		Hazardous Waste	(35)								0.21	ton	5,254	ton	0.09	ton
			Note:	Nap: Not Applicable; Aav: Not Available												

Source: The Author

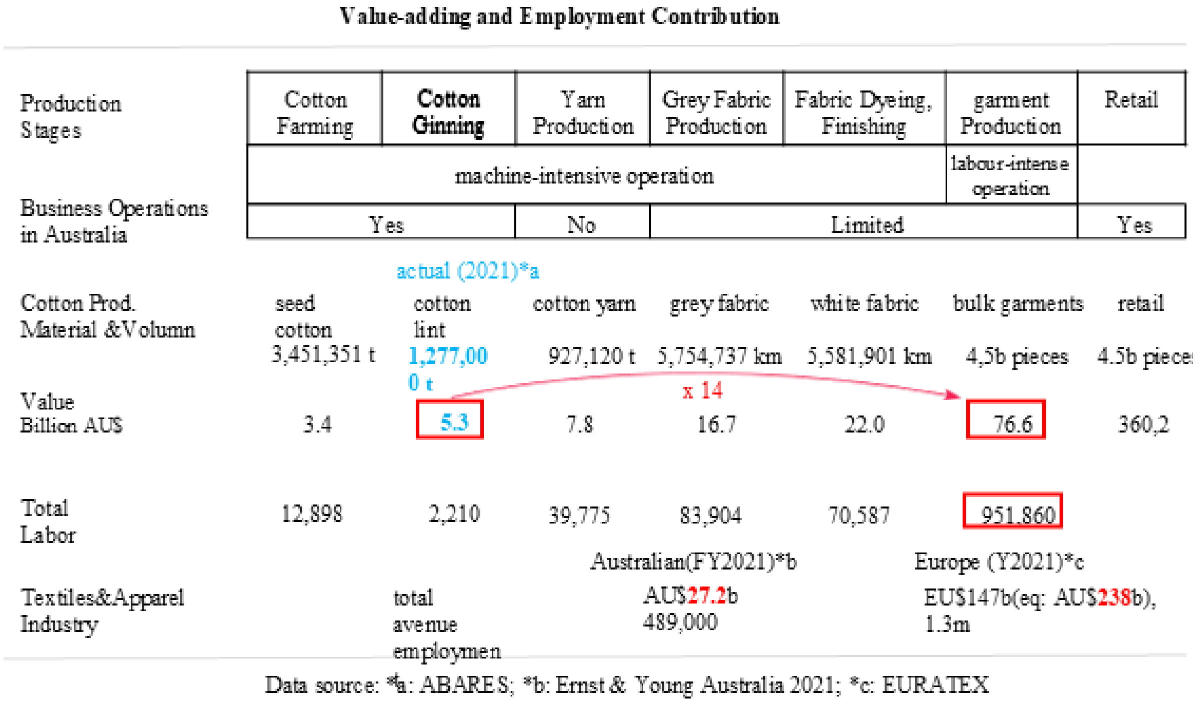
6.6 Findings

6.6.1 The TBL of the Australian Cotton Production from Seeds to Garments

Assessing the precise influence of Australian cotton in shirt manufacturing is complex due to the lack of specific data on its use in final products at this stage, as data is not gathered through case studies utilizing the PIODF framework. Nonetheless, the significance of this case study lies in demonstrating that the production impact of Australian cotton on a global scale is feasible when industrial data is available.

Although data is scarce, this case study has successfully identified critical production parameters in terms of value-adding and employment contribution, as shown in Figure 6.3, as well as resources consumptions and production discharges, as illustrated in Figure 6.4, noting data on resources and discharges, including fossil fuels, chemicals, and air pollutants, is unavailable at this stage due to time constraints. Moreover, these data indications that this evaluation may reasonably align with reality to some extent for the below reasons.

Figure 6.3: AU Cotton_ Value-adding and Employment Contribution



Value-adding and Employment Contribution

Production Stages	Cotton Farming	Cotton Ginning	Yarn Production	Grey Fabric Production	Fabric Dyeing, Finishing	garment Production	Retail
	machine-intensive operation					labour-intense operation	
Business Operations in Australia	Yes		No	Limited			Yes
		actual (2021)*a					
Cotton Prod. Material &Volumn	seed cotton 3,451,351 t	cotton lint 1,277,000 t	cotton yarn 927,120 t	grey fabric 5,754,737 km	white fabric 5,581,901 km	bulk garments 4,5b pieces	retail 4.5b pieces
Value Billion AU$	3.4	5.3	7.8	16.7	22.0	76.6	360,2
Total Labor	12,898	2,210	39,775	83,904	70,587	951,860	

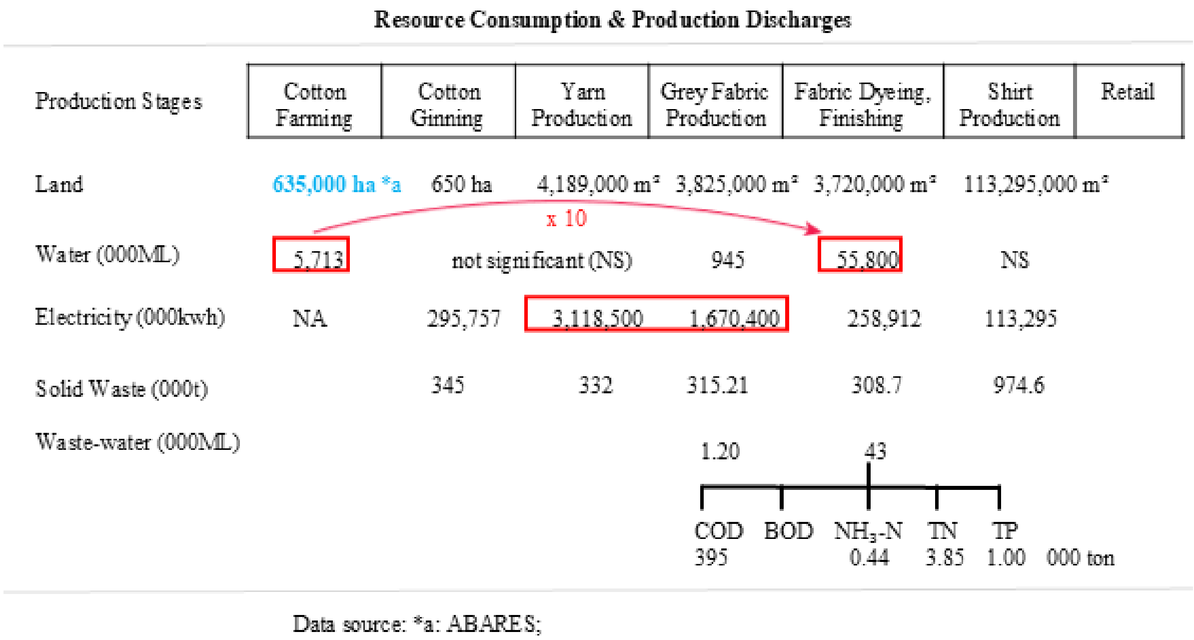
x 14

Textiles&Apparel Industry		Australian(FY2021)*b	Europe (Y2021)*c
	total avenue employmen	AU$27.2b 489,000	EU$147b(eq: AU$238b), 1.3m

Data source: *a: ABARES; *b: Ernst & Young Australia 2021; *c: EURATEX

Source: The Author

Figure 6.4: AU Cotton_Resource Consumption and Production Discharge



Resource Consumption & Production Discharges

Production Stages	Cotton Farming	Cotton Ginning	Yarn Production	Grey Fabric Production	Fabric Dyeing, Finishing	Shirt Production	Retail
Land	635,000 ha *a	650 ha	4,189,000 m²	3,825,000 m²	3,720,000 m²	113,295,000 m²	
Water (000ML)	5,713	not significant (NS)		945	55,800	NS	
Electricity (000kwh)	NA	295,757	3,118,500	1,670,400	258,912	113,295	
Solid Waste (000t)		345	332	315.21	308.7	974.6	
Waste-water (000ML)				1.20	43		

x 10

Data source: *a: ABARES;

Source: The Author.

Firstly, the assumptions used in the calculations are based on a diverse range of premises across all stages of the shirt production process. These varied assumptions are likely to counterbalance one another, including those related to other manufacturing processes of Australian cotton end-products. This mutual offsetting is commonly seen in various production practices, contributing to a more accurate overall portrayal.

Secondly, the calculations appear both consistent and plausible. The aggregate final figures seem to realistically reflect the industry's reality, lending credibility to the depiction of Australian cotton's impact through shirt manufacturing. This consistency bolsters the reliability of the estimated impacts, despite the absence of detailed usage data.

6.6.2 An Economic Opportunity for the Australian Cotton Industry

The production parameters illustrated in Figure 6.3 and Figure 6.4 highlight considerable economic prospects for the growth of the Australian cotton industry. The Australian cotton industry primarily focuses on cotton farming and ginning, with subsequent processes from yarn to garment production occurring abroad. Australian cotton exports are worth $5.3 billion, but their value escalates to about $76.6 billion when processed into garments overseas, adding $71.6 billion in value. These garments ultimately hold a retail value of approximately $360 billion, with most of this value being retained overseas.

The EY report (Ernst & Young Australia 2021), highlights that the fashion industry in Australia contributed $27.2 billion to the national economy in 2021, accounting for 1.5% of the Australian GDP and employing over 489,000 Australians, 77% of whom are female, thus playing a crucial role in providing economic security for Australian women. Currently, Australia seldom exports textile products, whereas in Europe, the textile industry accounts for 10% of the total GDP, making Europe the second-largest textile exporter after China.

This discovery underscores substantial economic growth opportunities for the Australian fashion industry, potentially increasing its GDP and employment contributions. The study also highlights water and electricity consumption as key challenges in expanding the Australian cotton supply chain domestically, providing vital insights for policymakers focused on enhancing the GDP and employment benefits of the fashion industry.

Therefore, Australia has significant opportunities to expand its textile business, with the establishment of a complete cotton supply chain being the most promising avenue for growth.

One of the major challenges in establishing a complete cotton supply chain in Australia is the substantial water consumption in the fabric dyeing, printing, and finishing sector. This sector uses nearly nine times more water than cotton farming. Such high-water usage raises significant concerns about the economic viability of including these processes within the supply chain. Additionally, this level of water consumption poses serious environmental concerns, as it can lead to water scarcity and increased strain on local water resources.

Another critical barrier is energy consumption. Yarn production consumes seven times more electricity than cotton ginning, highlighting a significant increase in energy demand at this stage. Similarly, grey fabric production requires six times more electricity than cotton ginning, further intensifying energy usage. The processes of dyeing, printing, and finishing consume a similar amount of electricity to cotton ginning, indicating that these stages are also energy intensive. In contrast, garment production, while still demanding, uses about half the electricity of cotton ginning. These high energy demands across various stages of the cotton supply chain present substantial challenges, both in terms of operational costs and environmental sustainability.

Further research with an enhanced IOPAM is necessary to develop a comprehensive report that addresses the economic, environmental, and social implications of this opportunity for the Australian cotton sector.

Chapter 7 Conclusions

7.1 Outcomes and Contributions

Time constraints have prevented the research from fully achieving its goals, although one of the objectives has been met so far. The efforts have been focused on developing the IOPAM, which was designed to steer the inquiry toward the ultimate research aim. The ongoing advancement of the IOPAM currently leads to three key outcomes that can benefit both industry practice and academia.

The first outcome lies in the enrichment of the PIODF) which supports data collection at the organizational level and ensures the research goals are met once data gathering and saturation are complete. The PIODF integrates the IOPMd and the IOPAM Components. The IOPM serves as a detailed framework that guarantees the integrity of the data collected and the analyses conducted within this structure, while the IOPAM components, presently tailored for the cotton clothing production sector, are adequate for data collection in this field. As a result, the PIODF establishes a solid foundation for the proposed PhD research and propels initiatives aimed at evolving production sustainability into a cutting-edge standard. This evolution is anticipated to commence at the organizational level, progressing to the sectoral level, and finally reaching the industrial level, thereby enhancing the overall production sustainability of the fashion sector. The PIODF is applicable to both industry and academia.

Organisations can employ this PIODF as a self-assessment instrument to chronicle their production data, thereby enabling production analysis that could identify TBL opportunities such as augmenting product value, optimizing resource utilization, diminishing production effluents, and enhancing worker conditions. Additionally, it has the potential to be utilized throughout the wider fashion industry and could even catalyse sustainability improvements in other sectors, as the fundamental principles of production remain constant across industries, irrespective of the presence of physical outputs.

Researchers have the option to adapt or employ the PIODF for gathering data that aligns with their unique field of study. Additionally, along with PIODF, a meticulously organized research design that offers a definitive framework for promoting production sustainability in the fashion industry, inviting focused research to aid in achieving cutting-edge production sustainability.

The second outcome is that a comprehensive foundation of practical knowledge regarding the cotton clothing production within the industry context is established, albeit open to further enhancement. This information encompasses 28 PIOFs that demonstrate as many as 100 processes, showcasing the transformation of materials, machinery, and labour into products, along with the associated discharges, although all of which require further refinement. Spanning from cotton seeds to completed garments, these processes are clearly presented, making them easily understandable to both industry professionals and academics, thereby fostering shared understanding. This knowledge also addresses a gap in the literature, as Sandin et al. (2019, page 109) acknowledged: "Knowledge of textile production processes is sparse and there is even less known about the environmental benefits and downsides of different techniques from a life cycle perspective." Hence, this knowledge is essential for research grounded in industry insights, as well as for the education about the clothing production.

The third outcome arises from a hypothetical case study assessing the global production impacts of Australian cotton. This case study not only highlights the effectiveness of IOPAM and the associated expertise but also reveals a significant economic opportunity for the Australian cotton industry to grow. Specifically, it suggests that establishing yarn production facilities in Australia could complete the production chain from seed to garment manufacturing. Key data insights include:

Industry Potential: Australia's textile and apparel industry has strong growth potential, especially when compared to Europe, whose revenue is nearly nine times larger. This is particularly impressive given that Australia is already a leading producer of premium wool and cotton.

Challenges and Solutions: Water and electricity consumption are identified as the primary barriers to industry expansion. However, these challenges can be mitigated through the adoption of advanced machinery and technology.

Alignment with Industry Advocacy: This finding aligns with the Australian Fashion Council's call to close the supply chain loop. It supports their recommendation for $2 million in funding for FY2025 to drive this initiative forward.

This case study also serves as a model for industry organizations to assess their production data, while also promoting more thorough research into the viability of achieving a complete cotton production chain in Australia.

All these outcomes and their contributions serve as key milestones of the research, reflecting its commitment to creating practical impacts, as it is motivated by the overarching aim of tackling a pressing global sustainability challenge within the fashion sector.

7.2 IOPAM Limitations

The current research has several limitations that warrant attention, but these can be addressed with further development.

Firstly, a discrepancy exists between field data and secondary data derived from literature. For instance, the ginning facility in Australia referenced in the case study possesses 6 gin stands. The daily output of this gin is 800-1000 bales per 24 hours, according to the onsite staff. However, if reference the North Queensland Cotton Gin Assessment and Feasibility Study Report, this gin's daily production should surpass 1600 bales in a 24-hour period. As a result, the case study estimated that 63 gin facilities are necessary to process Australian cotton. Should the 1600 bale figure be accepted, the requisite number of gin facilities would be around 40, which concurs with IBIS reports.

Another limitation is that the case study production documents, although based on hypothetical casual shirt production, were intended to reflect real industry operations. The author initially commissioned a production team to prepare critical documents such as individual shirt patterns, pattern markers, and sewing line planning. However, this effort did not succeed, and only the pattern layout document was adopted as originally intended. Despite this, the impact on the case study assessment was limited.

7.3 Future Research

7.3.1 PhD Research Proposal

The research is intended to be further developed at the PhD stage, with improvements focusing on the following key areas.

Complete and Improve Input-Output Production Analysis Methodology

As repeatedly highlighted, the methodology is a work in progress and necessitates further refinement. Areas identified for enhancement include, but are not restricted to:

- Development of social measures related to production.

- Formulation of entrepreneurial measures.
- Improvement of all existing measures.
- Enrichment of the methodology by integrating well-established theoretical frameworks such as quality control tools, lean production, Six Sigma, ISO standards(add), etc., following thorough investigation into these concepts.
- Amplification of the methodology through the integration of existing datasets from diverse Life Cycle Inventories after comprehensive analysis.
- Substantial supplementation of the methodology with case studies within the industry, which is crucial given that one of the aims of the methodology is to encourage adoption of practices that foster sustainable production within the industry.
- Enhancement of the methodology by investigating in-depth of the industry decision-making processes.
- Creation of an industrial report template, as an advanced methodology tool, that is concise and formatted for industry reporting, to facilitate the translation of academic findings into actionable insights for industry decision-makers.

<u>In-Depth Case Studies on Individual Entities within the Cotton Clothing Production Supply Chain</u>

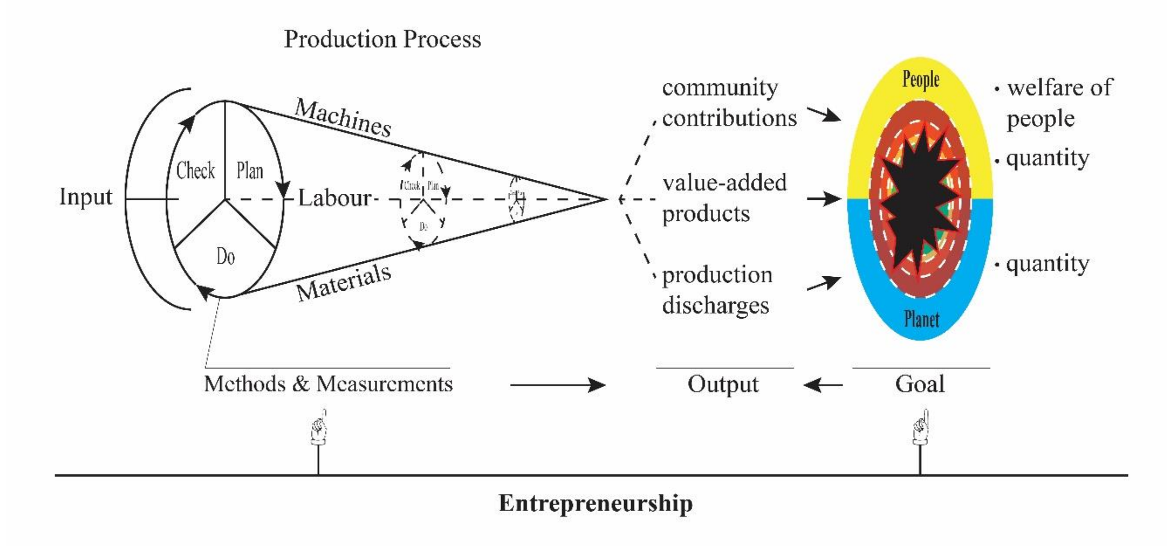
The key purposes for the case studies are to:

- Collect triple bottom line data within the methodology framework
- Observe entrepreneurship in production governance
- Identify the best practice and general practice

<u>Testing the hypothesis that entrepreneurship is the key to ensuring triple bottom line sustainability for fashion entities</u>

As a fundamental principle, businesses instinctively pursue profit, relying on resources and people. The issue arises when inputs are not directed appropriately, potentially sacrificing the environment or people's well-being for profit, as illustrated in Figure 7.1. Further research is intended to discover the relationship between the entrepreneurship and TBL sustainability.

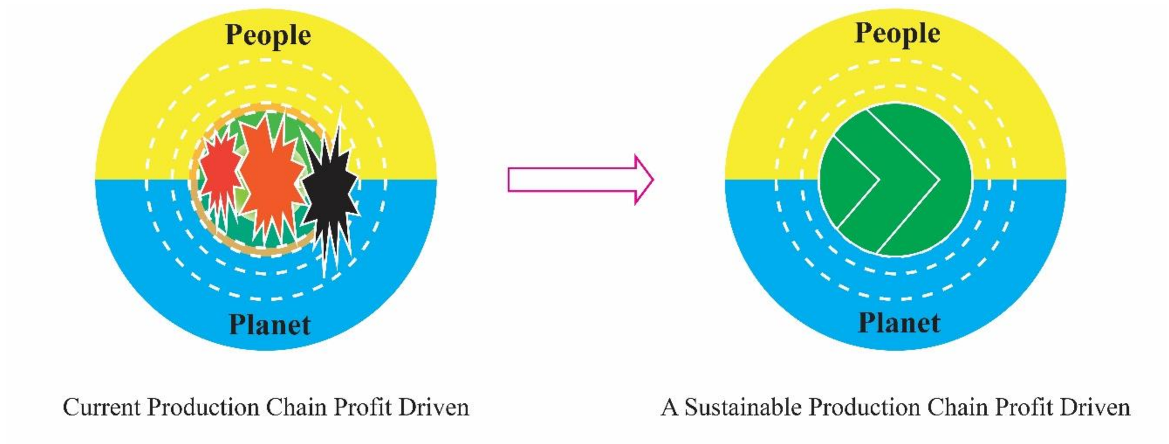
Figure 7.1: Unsustainable Production Model



Source: The Author

From a production chain viewpoint, while businesses may strive to meet their internal sustainability objectives, they frequently do not fully grasp the sustainability constraints of their downstream supply chain. This gap in knowledge can unintentionally result in unsustainable practices during price negotiations. Future research should focus on defining sustainable production chain boundaries. With collaborative efforts from academia, industry, and government, we can progress toward a more sustainable industry.

Figure 7.2: Transition from Current Production Profit Driven to A Sustainable Production Chian Profit Driven



Source: The Author

7.3.2 Other Research Areas

Reusing Wastewater for Cotton Farming

One significant area of research is the potential for treating wastewater from the cotton production chain to make it suitable for reuse in cotton farming.

Repurposing Cotton Production Waste

Another promising research area is exploring opportunities to repurpose cotton production waste for other industries.

While this study now concludes, it points to multiple opportunities for future research on Australian cotton, and more broadly, the sustainability of fashion and textiles. The collaboration between academia and industry, as demonstrated by this study, is essential for advancing this research.

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