**Thèse en cotutelle avec
l'Université de Boras (Suède) et l'Université de Soochow (Chine)**

Décisions de fabrication et modèle d'aide à la prise en charge à plusieurs niveaux pour améliorer la durabilité dans les chaînes d'approvisionnement en textiles et en vêtements

Manufacturing Decisions and A Multi-Tier Supply Location Decision-Support Model for Enhancing Sustainability in Textile and Clothing Supply Chains

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Errata:

'the submitted paper' in figures of Study 3 and the first working paper in Appendix F refer to the following published article:

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Manufacturing Decisions and a Multi-Tier Supply Location Decision-Support Model for Enhancing Sustainability in Textile and Clothing Supply Chains

Abstract

A recent trend towards sustainability has led to increases in various sustainable practices, but sustainability has still not been fully implemented into manufacturing and supply location decisions. A fragmented product supply chain (SC), which has various locations and multi-tier suppliers, leads to difficulties in traceability to ensure the SC has business, environmental, and social/socio-economic sustainability, known as the triple bottom line (TBL). Thus, this thesis aims to reveal which manufacturing decisions and location configurations better contribute to TBL, as well as to develop a location decision-support model for designing or evaluating multi-tier SCs with objective measurements and TBL factor considerations. Mixed methods are employed, including systematic literature reviews, semi-structured interviews, and SC simulations for the model formulation and its viscose t-shirt application. The thesis highlights that TBL benefits of proximity and distant manufacturing are location-dependent with their sources from spatial, cultural, ethnic, and linguistic proximity as well as country-, supplier-, and firm-specific. Spatial proximity benefits can be from proximity manufacturing to markets, materials suppliers, and headquarters as well as proximity between headquarters and market. The propose model has the potential to reveal the lowest or optimized cost and carbon dioxide equivalent (CO2e) SCs. The model is capable of revealing important factors and possible risks from future local and global disruptions, benefiting long-term supply chain planning. The model differentiates itself from the others by incorporating TBL from not only manufacturing and logistics activities but also sustainability assurance activities performed by suppliers and focal firms. The model potentially helps enhance TBL sustainability and supply chain visibility. This thesis has theoretical contributions to location theories, manufacturing decisions, cost and CO2e computational models, and sustainable multi-tier supply chain management.

Keywords: carbon emissions, global supply chain network design, location decisions, manufacturing decisions, supplier selection, supply chain performance measurement, sustainable supply chain management, total cost calculation

Tillverkningsbeslut och lokaliseringsbeslut för olika led i försörjningskedjan: Beslutstödsmodell för ökad hållbarheten inom textil- och klädindustrin

Abstrakt

Trots den senaste tidens trend mot ökad hållbarhet och utveckling av nya hållbara arbetssätt, finns mer att göra i samband med beslut om tillverkning och lokalisering. Dagens fragmenterade försörjningskedjor, med leverantörer på flera nivåer och olika produktionsplatser, har lett till minskad spårbarhet och svårigheter att säkerställa försörjningskedjans ekonomiska, miljömässiga och sociala hållbarhet. För att beskriva företags förmåga att säkerställa dessa tre hållbarhetsaspekter används begreppet the triple bottom line (TBL). Denna avhandling syftar till att bidra till ökad kunskap om vilka tillverknings- och lokaliseringsbeslut som påverkar TBL, samt till att utveckla en beslutsstödsmodell för utformning och utvärdering av flerskikts-SCs baserat på objektiva mätningar och olika TBL-faktorer. Studien innefattar en systematisk litteraturöversikt, semistrukturerade intervjuer och SC-simuleringar för modellutveckling med fokus på en specifik t-shirtapplikation.

Avhandlingen visar på att fördelarna med närhetstillverkning respektive avlägsen tillverkning beror på rumslig, kulturell, etnisk och språklig närhet samt på olika lands-, leverantörs- och företagsspecifika faktorer. Rumsliga närhetsfördelar innefattar närhet till marknader, materialleverantörer och huvudkontor samt närhet mellan huvudkontor och marknad. Beslutstödsmodellen har potential att avslöja de lägsta eller mest optimala kostnads- och koldioxidekvivalenterna (CO2e) SCs, och kan bland annat hjälpa till att avslöja möjliga risker kopplade till framtida lokala och globala störningar, vilket gynnar långsiktig planering av försörjningskedjan. Genom att inte bara ta hänsyn till företags tillverknings- och logistiksystem, utan också till deras hållbarhetssäkringsarbete, skiljer sig modellen från tidigare modeller. Avhandlingen bidrar till teoriutveckling inom platsteorier, tillverkningsbeslut, kostnads- och CO2e-beräkningsmodeller samt hållbar supply chain management i flera nivåer.

Sökord: koldioxidutsläpp, global design av leveranskedjans nätverk, lokaliseringsbeslut, tillverkningsbeslut, leverantörsval, prestandamätning i leveranskedjan, hållbar supply chain management, totalkostnadsberäkning

Décisions de fabrication et modèle d'aide à la prise en charge à plusieurs niveaux pour améliorer la durabilité dans les chaînes d'approvisionnement en textiles et en vêtements

Résumé

Une tendance récente au développement durable a entraîné une augmentation de diverses pratiques durables, mais le développement durable n'a toujours pas été entièrement mise en œuvre dans les décisions relatives aux lieux de production et aux approvisionnements associés. Une chaîne d'approvisionnement fragmentée (SC), avec une multitudes d'acteurs à différents niveaux et localisations, conduit à des difficultés de traçabilité et rend difficile le développement durable économique, environnemental et social, connue sous le nom de la triple performance (Triple Bottom Line TBL en anglais). Ainsi, cette thèse vise à définir les décisions en termes de production et configurations la chaîne d'approvisionnement qui contribuent le mieux au TBL, afin de développer un modèle d'aide à la décision de localisation pour la conception ou l'évaluation de SC à plusieurs niveaux avec des mesures objectives basées sur les facteurs du TBL. Des méthodes mixtes sont utilisées, y compris des revues de littérature systématiques, des interviews semi-structurées et des simulations de chaînes d'approvisionnement pour la formulation du modèle et sa mise en œuvre sur un t-shirt viscose. La thèse souligne que les avantages de la proximité et de la fabrication à distance sont tributaires de l'emplacement avec leurs ressources, des facteurs culturels, ethniques et linguistiques des pays des fournisseur et des spécificités des entreprises. Les avantages de la production locale peuvent être liés à la proximité avec les marchés, des fournisseurs de matières premières, et du siège social. Le modèle proposé permet de démontrer quelle est la chaine d'approvisionnement au coût le plus bas ou optimisé et l'équivalent en dioxyde de carbone (CO_2e). Le modèle est également capable de révéler des facteurs importants et des risques possibles liés aux perturbations locales et mondiales futures, ce qui permet une meilleure planification à long terme de la chaîne d'approvisionnement. Le modèle se différencie des autres études existantes en intégrant le TBL non seulement des activités de fabrication et de logistique, mais aussi des activités de développement durable effectuées par les fournisseurs et des entreprises locales. Le modèle contribue potentiellement à améliorer la durabilité et la visibilité de la chaîne d'approvisionnement sur les trois piliers du TBL. Cette thèse a des contributions théoriques sur la localisation, les décisions de production, les modèles de calcul des coûts et du CO2e, et à la gestion durable de la chaîne d'approvisionnement à plusieurs échelons.

Mots clés : émissions de carbone, conception de la structure d'une chaîne d'approvisionnement internationale, décisions de localisation, décisions de production, sélection des fournisseurs, mesure du rendement de la chaîne d'approvisionnement, gestion durable de la chaîne d'approvisionnement, calcul total des coûts, triple performance (TBL)

纺织服装供应链可持续制造与多层供应选址的决策支持模型

摘要

随着可持续发展的发展趋势形成了各种可持续发展实践的不断增加，但在制造地点和供应地点的决策中，可持续发展的研究成果仍未得到充分实施。分散的产品供应链（SC）具有不同的地点和多层供应商，这导致对产品难以进行追溯，无法确保产品供应链具有商业、环境和社会/经济可持续性，即三重底线（TBL）。因此，本文旨在揭示对商业、环境和社会/经济可持续性（TBL）有利的制造决策和位置配置，并开发一个基于客观测量和TBL多因素考虑的多层供应链（SC）的位置决策支持模型。本文提出了一个可实现持续性保障的多层供应点设计模型。本论文采用混合方法开展研究：系统文献综述与内容描述分析、半结构定性访谈、模型匹配和粘胶纤维T恤衫供应链实例分析。研究表明，商业、环境和社会/经济可持续性（TBL）对于制造点远近设置的优势取决于其所处的位置，包括地理位置、文化、民族和语言的相似性，空间邻近性的好处可以是制造业靠近市场、材料供应商和总部，以及总部和市场之间的距离。本研究建立的模型能够揭示供应链的最低或优化的成本和二氧化碳当量（CO2e）。该模型能够揭示未来供应链在局部和全球中断的重要因素和可能风险，有利于对供应链进行长期规划。涵盖商业、环境和社会/经济（TBL）的模型与其他模型不同，不仅包括制造和物流活动，还包括供应商和重点公司开展的可持续性保障活动。该模型有助于提高商业、环境和社会/经济（TBL）的可持续性和供应链的可视性。本文对选址理论、制造决策、成本和二氧化碳排放计算模型，以及可持续的多层供应链管理有一定的理论贡献。

关键词：碳排放、全球供应链网络设计、位置决策、制造决策、供应商选择、供应链绩效评估、可持续供应链管理、总成本核算。

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List of Abbreviations

ABC	Activity-Based Costing
AT	Austria
BD	Bangladesh
CH4	Methane
CN or CN(S)	China (Shanghai)
CN(N)	China (Nanjing)
CO2	Carbon Dioxide
CO2e	Carbon Dioxide Equivalent Emission
CSA	Country-Specific Advantage
DE	Germany
EF	Emission Factor
EG	Egypt
EXW	Ex Works term referring quoted prices of goods to be ready for transportation from a factory and exclude all logistics costs
GB	Great Britain
GHG	Greenhouse gas
GWP	Global Warming Potential
ID	Indonesia
IN	India
IT	Italy
LCA	Life Cycle Assessment
LT	Lithuania
N2O	Nitrous oxide
NREU	non-renewable energy use
PL	Poland
REU	Renewable energy use
RQ	Research Question
SLR	Systematic Literature Review
TBL	Triple Bottom Line referring to business, environmental, and socio-economic sustainability
TH	Thailand
TN	Tunisia
TR	Turkey
US	The United State
WoS	Web of Science

GENERAL INTRODUCTION

A product supply chain involves many manufacturing stages, from raw material extraction, materials processing, and component manufacturing, to final product manufacturing, before the products arrive warehouses to serve consumer locally or globally. The locations of each manufacturing stage, hereafter referred to as multi-tier supply locations, can be located in proximity to each other or across the world. With trends toward sustainability, the geographical proximity and dispersion of multi-tier supply locations lead to the question of *which manufacturing decisions and location configurations have relatively superior capabilities to others to enhance business, environmental, and socio-economic sustainability*, hereafter referred to as the triple bottom line (TBL)? Manufacturing location configurations based on Weber's Theory of Location of Industries include proximity and distant manufacturing to markets or to materials source (suppliers) with or without agglomeration (co-location).

The complexity of multi-tier supply chains, whose locations of each supply chain stage can be either in proximity or dispersed to one another, leads to difficulty in choosing multi-tier supply locations, especially for TBL enhancement. *How can a focal firm choose each of multi-tier supply locations to enhance TBL sustainability in a product supply chain?* Surprisingly, few existing models and studies relating to supply location decisions consider the TBL and/or more than the 2^{nd}-tier suppliers, even though there have been increasing sustainability and traceability concerns. In this thesis, final product suppliers or manufacturers of a focal firm (a buyer or buying company) are considered "1^{st}-tier suppliers"; in turn, their suppliers are referred to as "2^{nd}-tier suppliers." Moreover, most models mainly focus on the business dimension relating to costs and profits with or without efficiency, lead-time, risks, and environmental aspects. Few models and studies consider the socio-economic dimension; and their decision solutions are based on subjective opinions of managers rather than objective performance measurement on supply locations and suppliers. This shows that developing a supply location decision model with objective measurement criteria and incorporated TBL factors for enhancing TBL sustainability is a challenging task that I aim to achieve in this thesis.

As such, in this thesis I aim to reveal which manufacturing decisions and location configurations have relatively better capabilities to others to enhance TBL, and how to make relevant decisions and design the configurations. These lead me to develop a supply location decision-support model with incorporated TBL factors and objective performance measures on supply locations to achieve sustainable multi-tier supply chains. The model should have analysis techniques that can reveal high-and optimized- performance supply chains in order to observe their manufacturing location configurations. Results from the analysis will serve as feedback to the first aim of revealing which manufacturing decisions and location configurations are relatively superior to others.

As the focus of my doctoral program is on sustainability of the textile and clothing industries, I focused on manufacturing decisions of managers from clothing retailers and applied the model in a viscose t-shirt supply chain.

To reveal manufacturing location configurations and to develop the model to have potential to solve practical problems on supply location decisions and sustainability, I based my research on the pragmatic paradigm, which allowed me to employ mixed methods research consisting of both the qualitative and quantitative approaches. Different methods and analyses from mixed methods potentially increase validity of thesis findings by comparing results from different perspectives. Using mixed methods also helps generate useful findings with pragmatic validity to produce intended outcomes, and practical relevance to more applications than one specific domain. I adopt sequential equally-weighted mixed methods for designing and integrating the three studies in this thesis. Results of each study are used in its subsequent study and are reported separately, but all are discussed together when answering the main research questions of this thesis.

I based my thesis on multidisciplinary knowledge and practices, including sustainability and sustainable practices, sustainable multi-tier supply chain management, location theories, international business and investment, manufacturing and business location decisions, supply location decision models, and cost/carbon dioxide equivalent (CO2e) calculations. After reviewing the multidisciplinary literature (Chapter 1), I found little on proximity manufacturing and its potential to enhance TBL, aside from its benefits on short lead-time and quick response for uncertain markets, while I found several articles on benefits of distant manufacturing from existing studies on manufacturing locations. Therefore, I firstly conducted a systematic literature review on the benefits of proximity manufacturing (Study 1), with the aim to find similarities and differences of the benefits across locations and TBL dimensions, as well as perceiving trends and absences in existing studies relating to proximity manufacturing. The findings of Study 1 enhance the literature of proximity manufacturing and manufacturing location decisions by revealing the potential to have proximity manufacturing of intensive-labor industries located in high-cost countries with TBL benefits. Study 1 shows the increasing trend of studies focusing on not only the business dimension but also the environmental and socio-economic dimensions. Therefore, I want to find out whether focal firms in the clothing industries perceive and experience TBL benefits of proximity manufacturing or not and what are other unrevealed benefits influencing different manufacturing location decisions. This leads to Study 2, where I use the findings from Study 1 relating to research methodology, four inductive business aspects, and benefits of proximity manufacturing. Additionally, I conduct an additional SLR to see whether recent studies mention proximity manufacturing.

The aim of Study 2 is to explore reasons why focal firms choose proximity or distant manufacturing, and in doing so, to reveal the TBL benefits of each. I interviewed managers from twelve companies and triangulated data with shop and showroom visits, materials given by the managers, and online data from company websites, including financial and sustainability reports. Study 2 shows many discovered TBL benefits of both proximity and distant manufacturing contributing to manufacturing location decision literature. Besides the revealed benefits, Study 2 helps me understand business contexts such as strategies, resources and capabilities, and external environments and stakeholders influencing the manufacturing decisions. These findings of Study 2 together with relevant studies reviewed in Chapter 1 are inputs to Study 3 in terms of performance criteria, activities/factors for cost and CO2e calculation, and analysis techniques. Study 3 has two parts: model formulation and application.

Study 3 involves formulating the twelve-step proposed model for designing sustainable multi-tier supply locations by combining knowledge from practices in Study 2 and existing studies. The model formulation is an iterative process with the model application in viscose t-shirt supply chain to improve the proposed model. Feedback from other researchers also helps improve the model. I use cost and CO2e as measurement criteria to be proxies for comparing performances of different supply chains. CO2e is used for measuring and normalizing greenhouse gas (GHG) emissions.

For cost and CO2e calculation, I adopt logic models for identifying activities and their inputs and outputs relating to cost and CO2e in the supply stages as well as intermediate and long-term outcomes toward TBL sustainability. The logic models help me find and include into my proposed model TBL factors from sustainable practices and sustainable assurance activities performed by suppliers and focal firms. These differentiate the proposed model of this thesis from other models and contribute to cost and CO2e measurement literature and practices because traditional cost and CO2e computation includes only manufacturing and logistics activities and overlooks sustainable practices and sustainability assurance activities. Additionally, I adopt activity-based costing techniques for allocating overhead and indirect costs and CO2e to each product unit.

In the supply chain selection step of the proposed model, exploratory data analysis is used to show the lowest cost and CO2e supply chains, as well as the optimized low cost and CO2e supply chains for each consumer market. The feedback feature from the evaluation step in the model helps users for long-term and risk planning by taking into account important factors and potential local and global risks from sensitivity and scenarios analyses. Finally, users can choose a final supply chain according to their cost and CO2e preferences and constraints.

I apply the model in the textile and clothing industry for designing supply locations of 1,800 viscose t-shirts for serving three markets. I imitate the situation that if I am a small business and want to produce sustainable t-shirts with optimized low cost and CO2e and environmental and social compliances, how can I choose where to source fibers and fabrics and produce the t-shirts? The model application demonstrates not only how to use the model in practice, but also yields insights into viscose t-shirt supply chains, such as locations and agglomerated stages of supply chains for achieving the 1% lowest cost and CO2e supply chains from the total 4,608 investigated supply chains; it also shows important cost and CO2e factors of the viscose t-shirt supply chain. Sensitivity analysis of the model application confirms that the model, especially the firm computational scope, gives robust outcomes. Different scenarios are analyzed due to the current trade war and findings from previous steps of the model, showing that factory visits for sustainability assurance and fiber manufacturing technology greatly impact cost and CO2e of all supply chains.

Study 3 contributes to knowledge on manufacturing location decisions, cost and CO2e modelling, and supply chain design by showing not only the lowest or optimized cost and CO2e supply chains, but also important factors and which supply chain stages should be in proximity and agglomerated in order to achieve low cost and CO2e for enhancing business and environmental sustainability. The proposed model has potential to enhance TBL sustainability because of incorporated TBL factors from not only manufacturing and logistics activities but also from sustainability assurance activities performed by suppliers and focal firms. The model also potentially enhances supply chain visibility, as users will have to know their suppliers of suppliers for using this model.

This thesis consists of four chapters, shown in Figure 0.1. Chapter 1 is a literature review on multi-tier product supply chains, sustainability in supply chains, location theories and manufacturing location decisions, and decision-support models for supply location decisions. Chapter 1 helps identify gaps in the literature leading to the thesis purpose. Chapter 2 shows research questions and methodologies of the thesis as well as Studies 1-3. Chapter 3 presents the results and analysis of each study. Chapter 4 discusses results from all studies in order to derive answers for the thesis research questions.

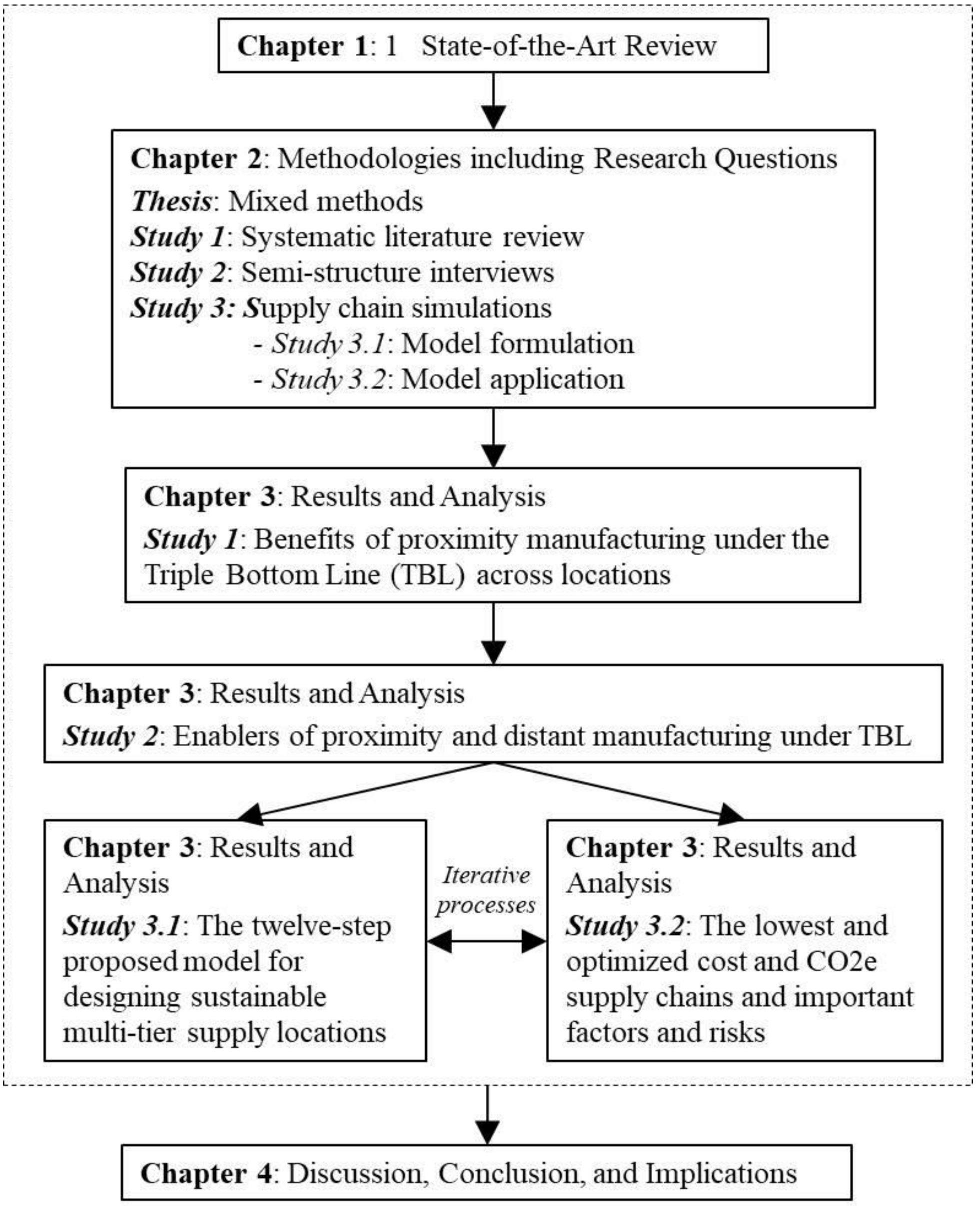

Figure 0.1 Structure of the thesis.

The discussion reveals that both proximity and distant manufacturing can gain TBL benefits from the following sources: spatial, cultural, ethnic, and linguistic proximity, as well as country-, supplier-, and firm-specific advantages. The proximity- and distant-manufacturing benefits are location-dependent. Spatial proximity can be any of proximity manufacturing to markets, materials suppliers, and headquarters, as well as proximity between headquarters and markets. I believe these noteworthy findings make theoretical contributions to location theory and manufacturing decisions research. Chapter 4 also includes the conclusion of the thesis findings, research limitations, and theoretical and practical contributions for researchers, industrial practitioners, and policymakers, relating the revealed benefits with their sources, the proposed model, cost and CO2e computational scope, location theories, and the model application in the textile and clothing industries.

1 State-of-the-Art Review

In order to create a decision-support model for supply location decisions towards product supply chain sustainability, it is important to know the structure of multi-tier supply chains, sustainability dimensions and sustainable practices, factors to be considered when making location decisions, and existing decision-support models shown in the following sections from 1.1-1.4.

1.1 An Overview of the Multi-tier Product Supply Chain

Multi-tier supply chain management and looking beyond the first tier of suppliers are nowadays vital to achieve sustainable supply chains, as most environmental and social issues occur at the sites of suppliers of suppliers (the second, third, …, N-tier of suppliers) (Tachizawa & Wong, 2014). Figure 1.1 shows the multi-tier closed-loop supply chain with supply locations applicable to most industries, though some industries may not have some stakeholders in their supply chains. For example, the food industry will not have repairing services and the recycling manufacturers are energy producers who will supply energy from burning waste to any stakeholders. Figure 1.1 also presents flows of objects (materials and goods), information, money, and carbon dioxide equivalent (CO2e) from energy consumption and energy generation among stakeholders in the supply chain. CO2e is used for measuring and normalizing greenhouse gas (GHG) emissions. Figure 1.1 is created after observing the thesis findings especially the interview in Study 2 and the multi-tier supply chains in Study 3. Besides stakeholders shown in Figure 1.1, other stakeholders outside the supply chain are governmental and non-governmental organizations (NGOs), and local communities who potentially influence, and are influenced by, the flows in the supply chain. Moreover, employees and workers are involved in every supply chain stage.

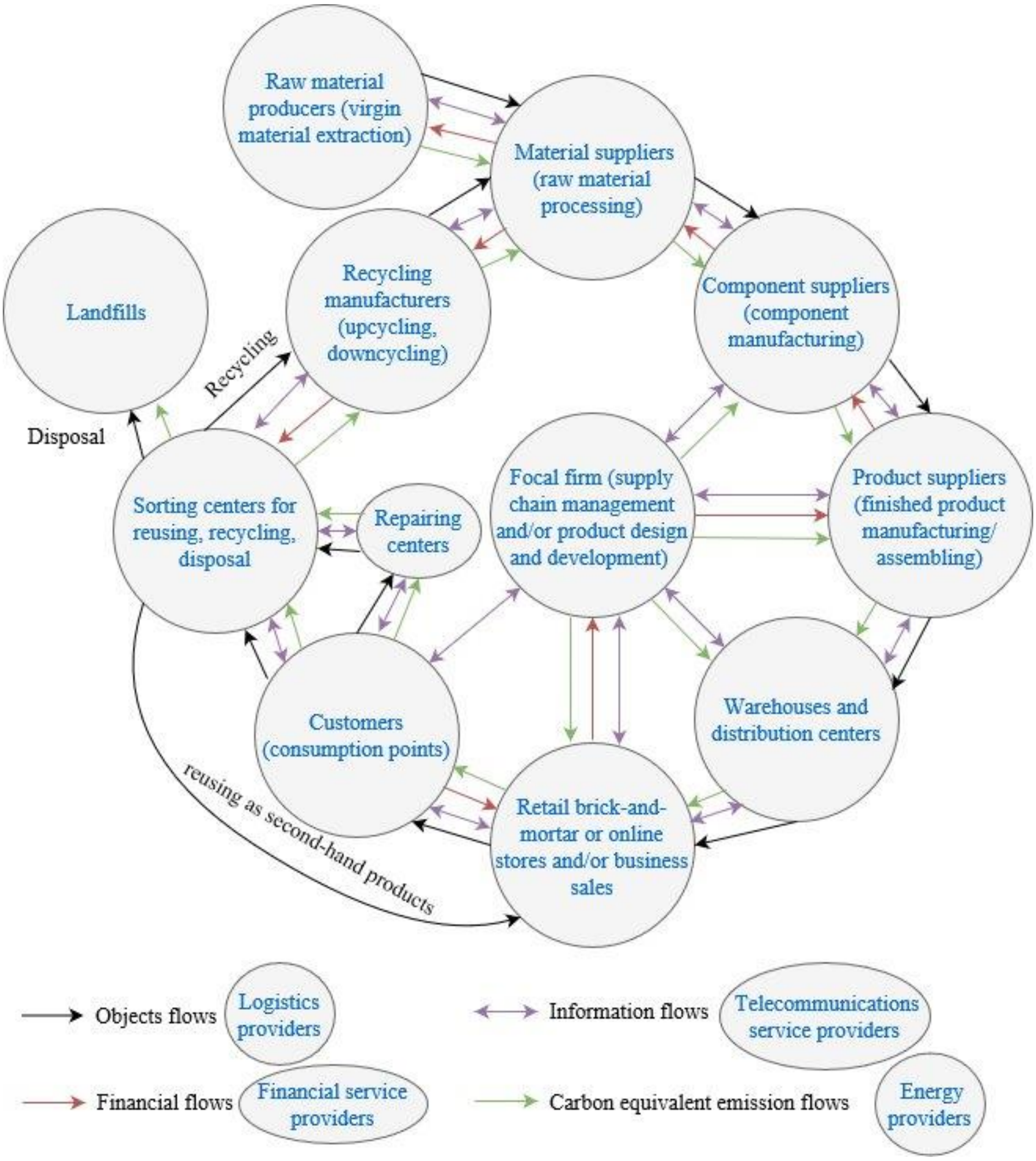

Figure 1.1 Structure of a multi-tier closed-loop supply chain showing object, information, financial, and carbon dioxide equivalent emission flows among stakeholders.

Remarks: The number and types of suppliers depends on industries; the flows from recycling manufacturers can be towards any other suppliers; product suppliers can be repairing centers; and main carbon dioxide equivalent emissions from focal firms to different stages of the supply chain are from governance activities such as site visitation.

Regarding multi-tier supply chain management literature, most studies mainly focus on the relationship between stakeholders in supply chains (Mena, Humphries, & Choi, 2013). These studies may be able to improve supply chain efficiency through better governance and collaboration, including information flow. However, there is still a lack of studies explicitly presenting measurable proven outcomes for enhancing TBL sustainability. Moreover, it is difficult for stakeholders within the supply chains (firms and their suppliers) to fully achieve high business and environmental performances of the supply chains when locational and transportation-related factors contribute to high cost and CO2e.

The textile and clothing supply chain is one of complex supply chains consisting of growing plants, producing fiber, spinning thread, knitting or weaving fabrics, dyeing yarns or fabrics, finishing fabrics, cutting fabrics, sewing garments, using garments, repairing garments, disposal or recycling garments as well as transporting fibers, fabrics, and garments to factories, warehouses, shops, consumer, and disposal or recycling sites. These activities may be located in proximity or distant to one another. However, it is common to see the activities are scattered around the world resulting in fragmented and complex supply chains which make management and traceability become difficult in order to ensure product quality, environmental sustainability, and social compliances (Tse & Tan, 2012).

1.2 Triple Bottom Line (TBL) Sustainability and Sustainable Practices

The Triple Bottom Line (TBL) concept (Elkington, 1998) was originally used in accounting reports by including business sustainability performance under environmental and social/socio-economic dimensions in addition to traditional accounting focusing on the economic dimension of business performance. The coverage of business, environmental, and social/socio-economic dimensions has made the TBL concept widely adopted for sustainable development and among academic researchers, especially in the SSCM studies (Khurana & Ricchetti, 2016; Li, Zhao, Shi, & Li, 2014; Seuring & Müller, 2008; Turker & Altuntas, 2014). Business performance relates to business survival and competition with others under financial, market, and governance contexts (Elkington, 2010). Environmental performance includes life expectancies of ecosystems, global warming concerns, and pollution relating to waste emissions and natural resource consumption from business operations. The social/socio-economic performance involves many stakeholders inside and outside a product supply chain such as workers, suppliers, consumers, local communities, societies, and nations (UNEP/SETAC, 2009). Relevant to this are working conditions, human and labor rights, ensuring worker health by using non-harmful chemicals in operations, and similarly ensuring consumer health by using non-harmful chemicals (Khurana & Ricchetti, 2016). Focusing on environmental and social/socio-economic performance helps businesses avoid reputational risks, guarding their brand value and helping them differentiate their brands from those of their competitors (Khurana & Ricchetti, 2016).

The traditional business measures focus on profits, cost, quality, flexibility, and delivery, including lead time, similar to competitive priorities for competitive advantage (Lin & Tseng, 2016). With the TBL concept, businesses include other stakeholders into their areas of focus, leading to implementation of sustainable practices, including Corporate Social Responsibility (CSR) programs for improving environmental and social/socio-economic sustainability (Padin et al., 2016). Sustainable practices can be implemented along a supply chain by different activities, such as product and process design (including development), purchasing and outsourcing, and materials and product logistics (Golini, Longoni, & Cagliano, 2014). Common practices for environmental sustainability in the textile and clothing supply chain are using sustainable materials such as organic fibers, green product and process design, technology implementation, factory and product certificates to ensure non-harmful chemicals, green logistics, traceability in the supply chain, and recycling and reuse (Caniato, Caridi, Crippa, & Moretto, 2012; B. Shen, 2014). Moreover, environmental problems at manufacturing sites of suppliers can negatively affect businesses by making problems affect the entire product supply chain (Elkington, 1994). Therefore, it is necessary to consider the entire life cycle and supply chain of a product. For social sustainability, the business attempts include social auditing by external or internal parties, initiating and implementing codes of conduct, applying fair-trade labels, and looking through suppliers of their direct-contact suppliers (Khurana & Ricchetti, 2016). Furthermore, most CSR programs were initiated at manufacturing sites and focused on improving worker living standards, as well as those of their families, and charity and other local community contributions. Though implementation of CSR programs may appear to increase costs to businesses, the businesses potentially increase their brand reputation and financial performance (Wu et al., 2015) as returned benefits on the CSR program investment, since CSR programs may create shared values by simultaneously giving benefits to both business and society (M. E. Porter & Kramer, 2006). Additionally, sustainable practices are varied among businesses according to their interpretation of the TBL concept, their focus on different TBL dimensions, available resources and capabilities to implement sustainable practices, and business strategies (Colbert & Kurucz, 2007; Glavas & Mish, 2015).

1.3 Factors for Manufacturing Location Decisions

As the focus of this thesis is on manufacturing location decisions, I used Alfred Weber's Theory of Location of Industries (Weber, 1929) as a basis to find factors relating to locations (shown in Chapter 1.3.1). As Weber's study was limited to one nation, it is necessary to investigate more factors from other studies involving local, international, reshoring, and offshoring manufacturing decisions (shown in Chapter 1.3.2).

1.3.1 Location Theories

According to the Weber's Theory of Location of Industries (Weber, 1929), the location theories of agriculture production and industries have been developed since 1900's and are based on economic theories such as the theory of rent and the equilibrium theory of supply and demand. The influencers on theory of the location include, but are not limited to, Johann Heinrich von Thünen for von Thünen theory of agricultural location, David Ricardo for Ricardian theory of rent, Adam Smith and John Stuart Mill for agricultural production, theory of rent, and supply and demand influencing price of products, Alfred Marshall for localization of industries to change, and Alfred Weber for Weber's location triangle focusing on production of industries leading to theory of the location of industries. Furthermore, Alfred Marshall and Alfred Weber are the explorers to find the causes of changing the locations of the manufacturing industries. Marshall raised an issue about "situation rent" that one can gain differential advantage over the other by locating themselves in more relative convenient situations (locations) with "less cost of carriage" for buying and selling things and with "close access to a labor market." Weber argued that locational factors may yield advantages for one location over another, as they may save costs in the production and distributing processes. Additionally, even with different research focuses, the findings among Thunen, Marshall, and Weber similarly showed land rents as differential advantages from reduced transportation costs due to shorter distances between manufacturing locations and their markets, as well as from wage differences.

According to Weber (1929), the cost of raw materials and power supplies, labor costs, and transportation costs of materials and finished products are considered general regional factors of location. Weber considered transportation and labor costs as the primary causes of the regional distribution of industry. The transportation costs vary according to plant location in relation to materials location and consumption, as well as infrastructure (mentioned by Weber as the length and nature of the road). The fundamental factors for transportation costs are weight and distance, with the focus of railway systems as the main transportation mode by land for German distribution of industries at the time. Other factors determining transportation costs are transportation mode, transportation infrastructure, and the nature of goods. The latter refers to whether the materials are available everywhere (ubiquitous) or only in specific places (localized) in relation to manufacturing location, and whether the weight of materials are lost (gross materials with residues) or remain constant (pure materials without residues) after manufacturing processes. Moreover, localized materials can be broken into two types: technically localized materials, such as minerals and coal; and economically localized materials, such as wood and wool, which are may be produced anywhere, but not economically. The secondary causes of the regional distribution of industry are agglomerative and deglomerative factors, which were treated together as a uniform agglomerating force (Weber, 1929). General and specific regional factors and agglomerative and deglomerative factors are gathered in Table 1.1 based on Weber (1929), Brush, A. Marutan, and Karnani (1999), and findings from Study 3.

Besides locational factors, Weber (1929) also noted how material availability and weight after processing, which determine transportation costs, influence the manufacturing locations, as shown in Table 1.2. Table 1.2 shows that manufacturing is located at the market when using ubiquitous materials or localized materials which gain weight after processing. On the other hand, manufacturing is located at the material source when using localized materials which lose weight after processing. The manufacturing location decisions by Weber (1929) are based on the uniform price of material among different sources under the assumption of finding manufacturing locations within one national boundary in Germany. Therefore, it is only partially useful and cannot be fully applied to the global manufacturing practices which are widely used among businesses to manufacture their products. Other factors must be considered and are shown in the following sub-chapter.

Table 1.1 Locational factors according to Weber's theory and additional factors from the other studies.

Application to industries	Regional factors	Agglomerative or deglomerative factors
Every industry (general factors)	The cost of raw materials and power supplies, labor cost, transportation costs of materials, finished products, **materials and product samples** (weight, distance, mode, infrastructure, nature of goods), **human (productivity, wages)**, profits of earlier stage as materials costs of later stages, **water cost, land cost (rent), social security, water and solid waste management fees and regulations, emission factors of transportation and electricity generation**	Using machinery together, auxiliary trade policies, sharing infrastructure (increasing purchasing and marketing power), *access to raw materials, energy, capital, and local technology*, and **transportation costs**
Particular industry (special factors)	Materials perishability, fresh water requirement, humidity and environment influencing to manufacturing process and depreciation of machines, quality and management of enterprises influencing interest rate, **trade regulations and duty fees, chemicals regulations, hazardous waste management, recycle regulations and infrastructure, renewable and non-renewable energy use rates and emission factors**	By product utilization, tariffs

Remarks: Bold indicates additional factors proposed by author based on results of the proposed model application; and italic indicates factors mentioned by Brush, A. Marutan and Karnani (1999).

Table 1.2 The transportation effects from material availability and weight on manufacturing locations basing on Weber's theory of the location of industries.

The number of material source	Material availability in		Material weight after processing*			The best manufacturing location towards		
	Every location	Specific location	Equal	More	Less	At source	At market	Any
One source (x)	x						x	
		x	x					x
		x			x	x		
		x		**x**			**x**	
Two sources (xx)	xx						x	
	x	x	xx				x	
		xx	xx				x	
	x	x			xx	x if material index > 1	x if material index < 1	x
		xx			xx	x of the material whose weight equal to the sum of the other and product weights		x
		xx	x		x	x of the weight-lessen material		x
	x	x	x		x	x if more weight-lessen material	x if more ubiquitous material	x
		xx		**xx**			**x**	

Remark: * is applicable to only specific-location materials; there is only one market; material index is calculated by the weight ratio of material and product; and bold indicates additional cases by the author basing on the Weber's theory.

1.3.2 Local, International, Reshoring, and Offshoring Manufacturing Decisions

As mentioned in the previous sub-chapter, there exists a link between economic theory and location theory. Therefore, the international business and economics literature, especially Dunning's eclectic theory of international production (Jonh H. Dunning, 1980), has been adopted by numerous studies, including studies on offshoring and reshoring manufacturing decisions (Ellram, Tate, & Petersen, 2013; Johansson & Olhager, 2018). The studies adopted Dunning's foreign direct investment advantages for location decisions, namely resource, market, efficiency, and strategic-asset seeking. Factors of location decisions during the 1970's period for achieving one of the four advantages mainly involve cost, while factors during the

1990's period involve specialization and quality of inputs, business agglomeration, and business infrastructure (John H. Dunning, 2009). Ferdows (1997) also observed that manufacturing locations were towards locations with skilled workers and advanced infrastructures, rather than locations with the lowest wages. Furthermore, strategic reasons of location decisions by Ferdows (1997) include the access to knowledge and skills, and to low-cost manufacturing, as well as the proximity to market, all of which are considered location factors in many studies (Johansson & Olhager, 2018). Similar factors can be seen in factor conditions, one of the four factors of national competitive advantage in the Porter Diamond Theory of National Advantage (M. Porter, 1990). The Porter Diamond consists of factor conditions, demand conditions, supporting industries, and firm strategy, structure, and rivalry. Porter presented the idea that both businesses and nations can be competitive and sustain competitive advantages through created factors, such as skilled workers and specialized knowledge, rather than endowment factors such as pool of labor and natural resources. Innovation, including improvement of resources, is a new perspective of competitiveness contrasting misperceived labor costs, economies of scale, exchange rates, and interest rates as competitive advantage sources; business and socio-economic sustainability can be enhanced in the long term. Moreover, home country-specific advantages (CSAs), such as regulatory frameworks and national competitiveness, potentially influence firm-specific advantages for competitive performances (M. Porter, 1990; Rugman, Oh, & Lim, 2012). CSAs relate to both home and host countries and can include factors of manufacturing location decisions. From the marketing perspective, consumer preference on products from countries with similar cultures implies nationality and national culture as a CSA (Rugman et al., 2012).

Studies relating to global supply chain location decisions focus on offshoring manufacturing at distant locations for resources such as materials and labor. On the other hand, studies relating to domestic, local, nearshoring, reshoring, and backshoring manufacturing at and nearby home countries of businesses and/or markets focus on how proximity manufacturing confers benefits of responsiveness to demand and ease of governing supply chains. Nearshoring refers to the manufacturing in low cost countries which are in proximity to home countries while reshoring and backshoring refer to moving manufacturing from a distant location to a new location in proximity to its home country. Some reshoring manufacturing does not involve returning to home countries, but rather to neighboring countries with relatively lower manufacturing costs (especially labor costs) in order to achieve low cost and benefits from shorter distances (Tate, Ellram, Schoenherr, & Petersen, 2014). Moreover, there have been trends of reshoring manufacturing back to home countries, especially in Europe (EU) and the United States (US) (Fratocchi et al., 2016). This is due to control and operations problems at host countries in distant locations, including delayed shipments, poor product quality, and non-confirming products (Gray, Esenduran, Rungtusanatham, & Skowronski, 2017; Kinkel & Maloca, 2009). Further reasons for reshoring include improved conditions of manufacturing inputs at home countries and relatively fewer benefits at host countries (Tate et al., 2014). Furthermore, most reshoring manufacturing involves products with automation and high technology intensity (Arlbjørn & Mikkelsen, 2014). Therefore, the possibilities and benefits for labor-intensive industries, such as the textile and clothing industries, to have manufacturing in high-cost countries -- especially in EU and US -- are limited, aside from the well-known reason of coping with demand fluctuation and uncertainty (Guercini & Runfola, 2004; Macchion et al., 2015; B. Shen, 2014).

According to the agglomerative and deglomerative factors previously mentioned in Table 1.1, the findings from survey by Brush et al. (1999) revealed that access to manufacturing inputs such as materials, capital, technology, and energy influenced decisions for agglomerating plants together at one location. However, access to manufacturing inputs is not important for decisions between domestic and foreign plants. Similarly, government subsidies, trade barriers, and exchange rate risks are the least important factors to the decisions, which is consistent with what M. Porter (1990) mentioned about misperceived competitive factors. On the other hand, proximity to main suppliers and customers is the most important factor of the decisions on domestic and foreign manufacturing in the Brush et al. (1999) survey findings. In addition to proximity to suppliers and customers, proximity to focal firm's facilities is also a major factor of location decisions shown in the Maccarthy and Atthirawong (2003) Delphi study on factors of international location decisions. Surprisingly, the local community's quality of life and competition are also major factors. Moreover, their findings showed that costs are still an important factor for international location decisions, together with the other previously-mentioned factors relating to business infrastructure, labor characteristics, and political and regulatory-related factors. Maccarthy and Atthirawong (2003) highlighted that factors of location decisions and their importance or influence vary according to geographical regions and business types.

Regarding factors for reshoring, Tate et al. (2014) showed important factors relate to the improved conditions of manufacturing inputs at home countries, including as labor productivity and cost stability, skilled workers, energy costs, exchange rate stability, and financial incentives. Relatively fewer benefits at host countries, such as the reduced gap of labor cost between host and home countries, delivery lead time, and currency and intellectual property risks are also reshoring factors influencing location decisions. Moreover, firms surveyed by Tate et al. (2014) seemed to overlook the long-term perspectives regarding labor and fuel costs, as well as consumer demand. Different scenarios should be assessed by scenario planning, including sensitivity analysis for the proper long-term decisions making (Tate et al., 2014).

Most studies on manufacturing location decisions mainly focus on the business dimension and overlook the environmental and social/socio-economic dimensions of sustainability. Chen, Olhager, and Tang (2014) reviewed studies on manufacturing facility locations and sustainability and showed that environmental factors mentioned by the studies are climate change, renewable resources, energy consumption, biodiversity protection, waste management, and recycling of energy, materials, and waste. Surprisingly, there is no environmental factor relating to emissions and energy consumption in transportation. This implies that the analysis level of the reviewed studies is not at the supply chain level, but rather at the site level, due to the lack of connection between sites. Factors relating to social/socio-economic dimensions are human rights and individual liberties, education, trade barriers, political stability, corruption, and safety, equity, technology, and cohesion in community. However, social/socio-economic factors relating to stakeholders in the supply chain (Figure 1.1) such as worker and consumer safety and protection are not shown in their review.

Specifically to textile, fashion and clothing industries, factors supporting garment manufacturing location decisions are similar to the above-mentioned factors and mainly involve in the business dimension. Factors for proximity manufacturing relate to specialized supplier availability, ability to control production and inspect products, short lead-time for fast replenishment and market quick response, capacity flexibility, similar culture for smooth operations, ability to provide high service level to customers, as well as complex, high fashion content, and make-to-order garment types (Bolisani & Scarso, 1996; Cammett, 2006; Forney, Rosen, & Orzechowski, 1990; Gray et al., 2017; Macchion et al., 2015). On the other hand, factors supporting distant manufacturing locations are relative lower cost, higher production skills, technology innovation, and special material availability at distant manufacturing locations (Forney et al., 1990; Macchion et al., 2015). The lack of industrial infrastructure, production technology, and production capacity at home countries are also factors for distant manufacturing (Forney et al., 1990; Gray et al., 2017). Moreover, Forney et al. (1990) showed that trade policies, pollution standard, and labor unions in the United States drove manufacturing preference to distant locations in that time.

1.4 Decision-Support Models for Supply Location Decisions and Performance Criteria

Current studies on models for sustainable supplier selection and management, including supplier monitoring and development, lack quantitative and social metrics (Zimmer, Fröhling, & Schultmann, 2015). As this thesis deals with developing a model for multi-tier supply location decisions for sustainability, I review existing studies on decision-support models and supply chain network designs for selecting manufacturing locations and suppliers in the upstream supply chain of non-edible consumer goods. Production and operation planning models that do not relate to strategic or long-term decisions for supply locations are beyond the scope of this thesis. I searched for recently published journal articles from 2017 to 2019 from the Scopus database by using key terms of model/design and location of supplier/manufacturing, and then read their abstracts in order to select relevant studies, the results of which are shown in Table 1.3 and Table 1.4.

Table 1.3 Objectives and methods comparison among location manufacturing and network design models from 2017-2019 published articles and this thesis.

Article	Objectives	Methods and techniques
1	Minimize summed costs of facility, outsourcing, and allocation and service to customers	Stochastic programming (normal approximation technique), a metaheuristic algorithm (an extended discrete colonial competitive algorithm), Monte Carlo simulation technique
2	Optimize manufacturing, storage, transportation, and carbon emission costs	Mixed integer linear programming (MILP)
3	Minimize costs and serve demand; investment and transportation trade-offs	Multi-period generalized disjunctive programming, a nonconvex mixed-integer nonlinear programming (MINLP), accelerated bilevel decomposition algorithm
4	Minimize fixed and operation costs with demand and return uncertainty	Two-stage stochastic MINLP, neightborhood search, an improved tabu search heuristic algorithm, diversification strategy
5	Optimize total costs of closed-loop supply chain with demand and return uncertainty	Scenario-based MILP
6	Reduce consumption rate and pollution emissions of vehicle fuel	Metaheuristic algorithms including simulated annealing, tabu search, bat, and variable neighborhood search
7	Lead time and order frequency impacts on supply chain design and costs	Mixed-integer programming with a deterministic discrete demand process
8	Minimize risk basing on cost, time, reliability, and inventory with certain, uncertain, and risky decision-making types	Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method and entropy weight method with normalized indicators
9	Minimize total costs of supply chain and maximize suppliers' equipment effectiveness values	Metaheuristic multi-objective evolutionary algorithm, a bi-objective MINLP, scenarios, Pareto fronts, the stochastic universal sampling selection mechanism, the epsilon-constraint method
This thesis	Minimize total cost and carbon dioxide equivalent emissions (CO2e) with sustainability assurance activities	MILP, Pareto fronts, exploratory data analysis

Remarks: Articles are [1]Alizadeh, Ma, Mahdavi-Amiri, Marufuzzaman, and Jaradat (2019), [2]Mishra and Singh (2019), [3]Lara, Bernal, Li, and Grossmann (2019), [4]Zhen, Sun, Wang, and Zhang (2019), [5]Srinivasan and Khan (2018), [6]Teimoury, Amiri, and Ketabchi (2017), [7]Hammami, Frein, and Bahli (2017), [8]Xu, Liu, Zhang, and Wang (2017), and [9]Perez Loaiza, Olivares-Benitez, Miranda Gonzalez, Guerrero Campanur, and Martinez Flores (2017).

Table 1.4 Industrial context, data source, and supply chain tiers comparison among location manufacturing and network design models from 2017-2019 published articles and this thesis.

Article	Industry/ product/ data source	Raw material supplier	Component factory[a]	Finish product factory	Warehouse[b]	Market	Sorting Center	Recycling
1	Auto-mobile, Iran		x	x		x		
2	Randomly generated dataset			x	x	x		
3	Biomass		x	x [c]	x	x		
4	Electric appliances, China			x	x	x		
5	Cartridge, India	x	x	x	x	x	x	x
6	Natural honey			x	x	x		
7	Automotive electrical harnesses, France		x	x	x	x		
8	N/A			x				
9	Automotive		x	x	x	x		
This thesis	Textile and clothing, locations in Europe, Asia, and America	x	x	x	x	same as ware-house	same as ware-house	same as component factory

Remarks: a and b include sub-contractors and distribution centers, respectively; c refers to centralized center; Articles are [1]Alizadeh et al. (2019), [2]Mishra and Singh (2019), [3]Lara et al. (2019), [4]Zhen et al. (2019), [5]Srinivasan and Khan (2018), [6]Teimoury et al. (2017), [7]Hammami et al. (2017), [8]Xu et al. (2017), and [9]Perez Loaiza et al. (2017).

Table 1.3 presents that model criteria of the studies mainly involve costs both with and without efficiency, risk, and environmental aspects. Criteria can be either qualitative or quantitative values for evaluating supply chain or supplier performances (Zimmer et al., 2015). Table 1.3 also presents that various methods and techniques are applied. Most of the studies employed mixed integer linear or non-linear programming. Moreover, most models were presented as mathematical modelling which seems to be difficult for industrial users to use the model for decision making. Therefore, I aim to create a location decision support model that is user-friendly.

In the upstream supply chain (supplier side) of the studies in Table 1.4, locations of finished product and component manufacturers considered the first- and second- tier suppliers (of brand retailers) are mainly focused on, while the location of raw materials, which is the third-tier supplier, are overlooked. Only Srinivasan and Khan (2018) included the third tier supplier and all stages in a closed-loop product supply chain. They also reviewed existing studies on closed-loop supply chain models published before 2017 showing that most of the studies used total cost minimization as an objective, scenario method for handling uncertainty, and mixed integer linear programing as a solution method. Furthermore, recent studies shown in Table 1.3, aside from Mishra and Singh (2019) and Teimoury et al. (2017), do not include the environmental dimension, and none of them incorporate the social dimension into their models. Therefore, I reviewed older existing studies and found only one study by Dou and Sarkis (2010) incorporating TBL factors into a proposed model of offshoring outsourcing decisions for facility location decision and supplier selection. However, their model is complex and difficult to implement due to an excessive number of involved factors and their interdependencies. Moreover, their analytical network process modelling is based on subjective managers' opinions for pairwise comparisons among factors rather than on objective measured performance among different locations and suppliers. Therefore, I aim to create a supply location decision-support model with three tiers of suppliers and TBL sustainability considerations, as shown in the last row of Table 1.3 and Table 1.4.In my proposed model, cost and CO2e will be used as proxies to measure supply chain performances from manufacturing, logistics, and sustainability assurance activities in a product supply chain. CO2e is used for measuring and normalizing the main GHGs: carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Performance criteria and calculations are also adapted from other supply network design studies which do not appear during the search in the Scopus database (C. T. Kuo & Lee, 2019; T.-C. Kuo, Tseng, Chen, Chen, & Chang, 2018) or published earlier than 2017 (Chaabane, Ramudhin, & Paquet, 2010; Nouira, Hammami, Frein, & Temponi, 2016; Ramudhin, Chaabane, & Paquet, 2010) mentioned in the following paragraphs.

C. T. Kuo and Lee (2019) used Pareto optimization to offer minimized cost and environmental impact solutions to aid in designing gardening shear product supply chains. They calculated environmental footprint impact using the Simapro software with the midpoint method (ILCD 2011). The software do not provide complete and updated data. Moreover, their calculation was based on material/component quantities, power consumption in manufacturing stages, supplier's production capacity, and transportation distance. Cost and environmental impacts from sustainability assurance activities are still overlooked. T.-C. Kuo et al. (2018) designed supply networks with cost and carbon emission criteria concerning supplier locations and manufacturing capacity. They considered carbon emissions from electricity consumption, but overlooked different localized emission factors (EFs) of electricity generated in different locations. Electricity in each location is generated by different energy sources, which vary electricity EFs and thus lead to different carbon emissions. Therefore, their designed supply chain network could be changed if electricity EF of the proximity location were much more than of the distant location, because low transportation carbon emission from short distance may not help decrease the total carbon emission in a supply chain if the proximity manufacturing location uses electricity from non-sustainable sources of energy, as shown in the Reich-Weiser and Dornfeld (2009) study.

The Nouira et al. (2016) study involved carbon emissions from different production technology, as well as different transportation modes and distances. Their study is differentiated from others by focusing on revenue relating to emission-sensitive demand rather than cost. Their scope included only component and finished product suppliers, as well as warehouse without raw materials suppliers. Moreover, their carbon emission calculation did not include emissions from electricity generation. Ramudhin et al. (2010) also considered the influence of production technology on carbon emissions. They studied make or buy decisions as business strategies and buy or sell decisions of carbon credits as environmental strategies based on cost and carbon emissions. Their updated research is shown in the Chaabane et al. (2010) study investigating CO2e by life cycle assessment (LCA). They assessed all forms of inputs and outputs such as gas, solid, liquid, and energy.

The above-mentioned studies show the necessity of including both manufacturing and transportation activities, as well as considering different production technologies and EFs of electricity generation among different locations, when calculating carbon emission and other CO2e in a supply chain. Additionally, in order to make sustainable manufacturing location decisions for product supply chain sustainability, multi-tier supply locations as a network must be considered.

1.5 Summary of Gaps in the Literature and the Thesis Purpose

Weber's Theory of Location of Industries presents both regional and agglomerative factors applicable to both general and specific industrial contexts, as shown in Table 1.1. In most cases, the best manufacturing locations are near-to-market when materials are available everywhere, and near to the material source when the materials lose their weight during processing, as shown in Table 1.2. The Weber's (1929) findings are good bases for manufacturing location studies. The Weber's (1929) location theory can be improved to meet current manufacturing circumstances because the Weber's (1929) study was under the assumptions of uniform material price and one national boundary for finding manufacturing locations. Today's manufacturing practices are global, with each location having different resources and technology, leading to different manufacturing costs before including transportation costs. Therefore, his theory and factors need to be updated for current global manufacturing.

Studies on manufacturing location decisions relating to local, nearshoring, offshoring, and reshoring manufacturing mainly involve Dunning's four location advantages: resource, market, efficiency, and strategic-asset seeking. Endowment factors for resource and market seeking seem to be important factors before the 1990's, and after that innovation, quality, and infrastructure related factors for efficiency and strategic-asset seeking seem to become more important. Reviewing existing studies reveals that most factors of manufacturing location decisions involve the business dimension, and few involve the environmental and social/socio-economic dimensions. Moreover, most business factors relate to offshoring and foreign location decisions; factors relating to local and proximity manufacturing are still limited. Therefore, I conduct a systematic literature review in Study 1 to reveal additional factors and benefits of proximity manufacturing under TBL. Furthermore, I focus on the textile and clothing industries, which can represent labor-intensive industries whose nature opposes high-cost manufacturing.

As shown above, the lack of important TBL factors for manufacturing location decisions could be a reason why existing models for manufacturing location decisions and supply chain designs typically do not incorporate all TBL dimensions. Therefore, it is necessary to update current important factors of manufacturing location decisions for both proximity and distant manufacturing from practitioners, especially factors relating to environmental and social/socio-economic sustainability enhancement. The empirical study by semi-interviewing managers of twelve clothing brands o explore current sustainable factors for manufacturing location decisions will be conducted Study 2. After that, Study 3 will develop a decision-support model of multi-tier supply location decisions for sustainable product supply chains with TBL factors, as most models for manufacturing location decisions and supply chain design proposed by existing studies do not concern all TBL dimensions and multi-tier supply locations, as shown in Table 1.3 and Table 1.4. The model formation will be in Study 3.1 and its application in the textile and clothing industry will be in Study 3.2 which shows how to design a new viscose supply chain and, as well as reveal important factors and possible risks for long-term strategic supply chain planning and management.

2 Methodologies including Research Questions

I aim to reveal whether proximity or distant manufacturing yields a relatively better supply chain in terms of enhancing TBL. This will later help me to achieve another aim, to develop a manufacturing location decision-support model incorporating TBL factors and objective performance measures on manufacturing locations to achieve sustainable multi-tier supply chains. According to Chapter 1.3.1 of Weber's Theory of Location of Industries, manufacturing locations can be either proximity or distant manufacturing to market or materials source (suppliers), with or without agglomeration between stages. "Manufacturing locations" refers to either outsourced or in-house manufacturing locations of focal firms, which are firms who govern product supply chains. The model should have analysis techniques that can reveal high-performance supply chains, i.e. those with very low cost and/or CO2e, to observe their manufacturing locations. Results from the analysis will be used towards the first aim of revealing which manufacturing location is superior in enhancing TBL.

2.1 Thesis Research Design

Originally, the main purpose of my research was to study whether and how proximity manufacturing enhances TBL and if it is a sustainable practice for focal firms to make sustainable manufacturing location decisions. However, focusing on only proximity manufacturing without comparing it to distant manufacturing/offshoring cannot guarantee that proximity manufacturing is the relatively superior choice for manufacturing decisions towards TBL enhancement. Therefore, in this thesis I aim to study all manufacturing location decisions, and models with the TBL concept. These lead to the first research question (RQ) of the two main RQs of this thesis.

RQ1: How do different manufacturing location decisions enhance TBL? This research question helps reveal benefits of different manufacturing locations to each TBL, revealing which one is better than the others.

The literature review in Chapters 1.3 and 1.4 shows that few studies on manufacturing location decisions and models are based on all TBL aspects, though there are trends towards sustainability and sustainable practices. There is also a lack of manufacturing location decision models incorporating TBL with objective measurements. With complex and dispersed supply chains, most of the existing studies still focus only on comparing business and/or environmental performance of individual locations of one supply stage, especially 1^{st}-tier suppliers, rather than of connected supply locations of several stages from raw materials manufacturing to the 1^{st}-tier suppliers. Therefore, the second RQ of this thesis is as follows.

RQ 2: How can a focal firm objectively choose manufacturing locations of each supply stage for enhancing sustainable multi-tier supply chain of a product? This research question helps present steps for manufacturing location decisions, leading to the formulation of a decision-support model based on TBL factors and objective measurements for choosing multi-tier supply locations of a product supply chain towards sustainability. Additionally, the answers of RQ 1 will help to answer RQ 2.

As both RQ 1 and RQ 2 are based on practical problems on manufacturing decisions and sustainability, I adopt pragmatic research paradigm with mixed methods in this thesis in order to produce valid and useful outcomes for real world applications through answering the RQs. Pragmatism acknowledges uncertainty and relative (not absolute) produced knowledge, leading to flexibility and unexpected emergent data (Yvonne Feilzer, 2009). This potentially helps this thesis reveal new knowledge relating to sustainability and proximity manufacturing from well-developed manufacturing location decision knowledge, shown in Chapter 1.3. The pragmatic paradigm supports the employment of both qualitative and quantitative approaches, known as mixed methods, in research without conflicting views.

Mixed methods potentially help this thesis provide multiple perspectives on manufacturing location decisions towards TBL and attenuate risks from method bias (Golicic Susan & Davis Donna, 2012). The research design of this thesis is based on sequential equally-weighted mixed methods, known as the development design (Golicic Susan & Davis Donna, 2012). The development design allows results of each method to be reported separately and used in its subsequent method, as seen in Figure 2.1. Figure 2.1 shows that the results of each method help answer RQ 1 and RQ 2, which will be discussed in Chapter 4 Discussion, Conclusion, and Implications, along with the highlights on common and contrasting results from each method and with the other studies. In addition, I adopt systems thinking (Arnold & Wade, 2015) for design this thesis, and I will discuss the interrelationships among the different results and their synergies to answer RQ 1 and RQ 2 in Chapter 4.

For the sequence of each method in my mixed methods research, I chose to conduct the qualitative research, i.e. the interview (Study 2), before the simulation research (Study 3) because the former has potential to help me explore well-known concepts of manufacturing location decisions and models in a new context relating to a sustainability perspective (Golicic Susan & Davis Donna, 2012). Study 2 enhances my understanding of different kinds of manufacturing location decisions relating to TBL, which allows me to conduct the Study 3 supply chain simulations for the formulation and application of the proposed model. Besides the Study 2 findings, measurement criteria, activities, and factors in Study 3 are derived from the review of existing studies in Chapter 1.

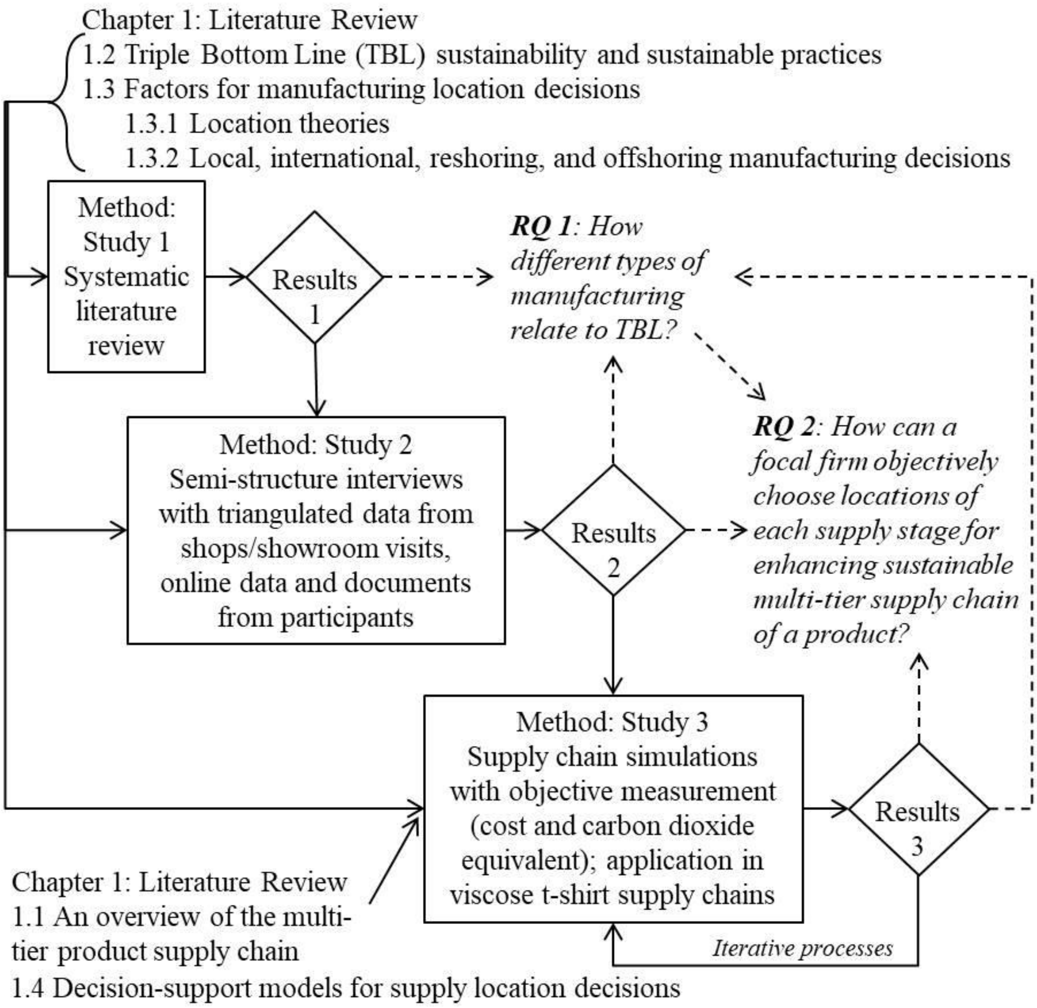

Figure 2.1 The thesis research design with sequential mixed methods.

Before conducting the Study 2 interview research, I conducted a systematic literature review on existing studies in Study 1 to reveal benefits of proximity manufacturing across TBL and locations to be used in Study 2. The reason is that few benefits of proximity manufacturing, especially relating to TBL and labor-intensive manufacturing in high-cost countries are mentioned in existing studies in Chapter 1.3. Additionally, the TBL concept and sustainable practices in Chapter 1.2, as well as factors for manufacturing location decisions in Chapter 1.3, helps in collecting, organizing, and analyzing data in all studies.

To fit the focus of my doctoral program, all three studies specifically involve the textile and clothing industries. Focusing on one industry gives insights into studied contexts that influence findings. This helps ensure accurate interpretation and enhances validity (Yvonne Feilzer, 2009). Though all the findings of the three studies are based on the textile and clothing industries, the discussion in the last chapter will show how results of all studies help answer RQ 1 and RQ 2 in wider industrial contexts, i.e. in similar industries and products.

For validity enhancement, employing mixed methods and focusing on only the textile and clothing industry helps provide different perspectives and insights into studied contexts, aiding analysis and appropriate interpretation of findings (Yvonne Feilzer, 2009). This thesis focuses on not only internal validity but also pragmatic validity and practical relevancy according to the pragmatic paradigm (Oliva, 2019). The validity activities involve using triangulated data (Golicic Susan & Davis Donna, 2012), identifying patterns of results, understanding what (contexts/circumstances) causes results (Yvonne Feilzer, 2009), repeatedly comparing and contrasting results with theories and existing studies (Wilhelm, Blome, Bhakoo, & Paulraj, 2016) , and reflecting what works in the real world, showing capabilities in producing intended outcomes (Oliva, 2019).

The following subsections show Study 1- Study 3 with their aims, desired outcomes, and research questions relating to the main research questions of this thesis (RQ 1 and RQ 2), as well as methods and analysis approach.

2.2 Study 1 Systematic Literature Review

Existing studies, as shown in Chapter 1.3, do not explicitly show benefits of proximity manufacturing, especially under the environmental and social/socio-economic dimensions;

therefore, this study aims to reveal benefits of proximity manufacturing under each TBL across various locations by systematically reviewing peer-reviewed journal articles. Systematic literature review (SLR) has the potential to generate data which are rigorous and replicable, and has been used in many studies to fulfill knowledge relating to supply chain management (Centobelli, Cerchione, & Esposito, 2017; Peter, Richey, & Scott, 2017; Pittaway, Robertson, Munir, Denyer, & Neely, 2004). I conducted SLRs twice. One was during the year 2016 and 2017 and the other was in 2020 in order to update the knowledge. The findings of Study 1 help answer RQ 1 and potentially drive more research and business practices on proximity manufacturing for sustainability enhancement.

I used the SLR guidance by Denyer and Tranfield (2009) together with Durach, Kembro, and Wieland (2017), whose study is dedicated to SLR in supply chain management. Furthermore, I used the TBL concept from Chapter 1.2 to classify extracted benefits of proximity manufacturing from the reviewed articles. This helps point out how proximity manufacturing benefits each TBL dimension.

RQs of this study, as shown below, are fundamental to retrieving and selecting relevant literature studies, as well as coding and synthesizing the literature (Durach et al., 2017):

RQ 3: What are proximity-manufacturing benefits of the textile and clothing industry in each market location under each TBL dimension?

RQ 4: How has proximity manufacturing for the textile and clothing industry been studied across time in terms of methods, studied contexts (product and market locations), and TBL dimensions?

RQ 3 helps reveal the similarities and differences of proximity-manufacturing benefits among different locations and TBL dimensions, while RQ 4 helps reveal gaps and trends from existing studies guiding research in the subsequent study. The benefits can be referred to as positive factors of manufacturing location decisions.

2.2.1 Article Retrieval by Search Strings

The articles were searched for in Web of Science (WoS) and Scopus, which contain peer-reviewed articles from various disciplines. To avoid excluding relevant primary studies, I did not limit the search to only high-ranked journals. The search strings were constructed by "proximity manufacturing, sustainability, and clothing" terms and their synonyms. I use inclusion and exclusion criteria, as shown in Table 2.1, to help article searching and selection in order to avoid bias and enhance validity. WoS and Scopus databases show the search results of 95 and 363 article hits, respectively.

Table 2.1 Inclusion and exclusion criteria.

	Inclusion criteria for articles	Exclusion criteria for articles
1	From year 1900*-2016**	From non-peer reviewed journals
2	From any journals in the databases	With non-English language
3	With any locations of studied context	Without clothing industry
4	With any types of research	With only yarn or fabric manufacturing
5	With any research topics of shown articles by search strings	Without proximity manufacturing or with other sustainable practices
6	Presenting benefits and factors of proximity manufacturing to any business, environmental, and social/socio-economic dimensions	Without clearly stating proximity manufacturing benefits or with only disadvantages and problems of global manufacturing

Remark: *the search results showed the earliest-year article published in 1997, ** up to the time of conducting the systematic literature review whose results are used in the subsequent study. The recent studies from January 2017 to June 2020 are reviewed and reported in the last section of Study 1.

2.2.2 *Article Selection by Manual Screening*

From the 458 articles appeared from the search, I found 96 potential primary studies to be read in detail by deleting redundant articles between the two databases and irrelevant articles whose abstracts match the exclusion criteria and do not match the inclusion criteria in Table 2.1. Finally, 45 articles present benefits of proximity manufacturing and were remaining as the primary studies for content and descriptive analyses. The 45 primary studies are shown in Table 2.2, and present the same list as the peer-reviewed paper which I published with my supervisors (Sirilertsuwan, Ekwall, & Hjelmgren, 2018).

Table 2.2 Chronological list of the 45 primary studies from Sirilertsuwan et al. (2018).

	Primary study		Primary study
1	Buxey and Kosmider (1997)	24	Pickles and Smith (2011)
2	Godley (1997)	25	Styles, Schoenberger, and Galvez-Martos (2012)
3	Zakim (1999)	26	Choi (2013b)
4	Scott (2002)	27	Goto (2013)
5	Adler (2004)	28	Kadarusman and Nadvi (2013)
6	Su, Gargeya, and Richter (2005)	29	McCaffrey (2013)
7	Jin (2005)	30	Choi (2013a)
8	Van Dooren (2006)	31	Choi (2013c)
9	Peters and Hertwich (2006)	32	Cao et al. (2014)
10	Edensor and Kothari (2006)	33	Zhu and He (2014)
11	Amberg (2006)	34	Zhu and Pickles (2014)
12	Towers and Peng (2006)	35	Jaegler and Burlat (2014)
13	Oh and Kim (2007)	36	Orcao and Pérez (2014)
14	Abaza (2007)	37	Jung and Jin (2014)
15	Smith, Pickles, Bucek, Begg, and Roukova (2008)	38	Bonilla, Keller, and Schmiele (2015)
16	Courault and Doeringer (2008)	39	Pickles, Plank, Staritz, and Glasmeier (2015)
17	Lowe (2009)	40	Plank and Staritz (2015)
18	Steinberger, Friot, Jolliet, and Erkman (2009)	41	Zhu and Pickles (2015)
19	Lau, To, Zhang, and Chen (2009)	42	Sardar, Lee, and Memon (2016)
20	Chang and Ha-Brookshire (2011)	43	Nouira et al. (2016)
21	Wang, Gilland, and Tomlin (2011)	44	Uluskan, Joines, and Godfrey (2016)
22	Pamuk and Williamson (2011)	45	Plank and Staritz (2016)
23	Abedniya and Zaeim (2011)		

2.2.3 Information Extraction by Content and Descriptive Analyses

Content and descriptive analyses were used as coding structures for extracting information from the 45 primary studies. Content analysis (Krippendorff, 2004) and descriptive analysis help demonstrate artifacts of the primary studies across timelines, such as methods, locations of studied context, and TBL dimensions for RQ 4. Content analysis, together with TBL dimensions, is used to extract benefits of proximity manufacturing for RQ 3 and to categorize the benefits into groups relating to business, environmental, social/socio-economic sustainability. I use a table with 45 studies in columns and extracted benefits in rows. The table helps compare results from the studies. Common results from many studies enhance validity and reliability of the findings. Moreover, similar benefits were placed next to one another during the extraction, which helps reveal groups from the extracted benefits under each TBL.

In addition, further details of methodologies can be found in Sirilertsuwan et al. (2018), such as the flow chart of article retrieval and selection process, reasons of inclusion and exclusion criteria, the search term strings, and an example of the table used for extracting factors from the primary studies.

2.2.4 Updating Knowledge from Recent Studies Published in 2017-2020

After the SLR on the 45 primary studies published until December 2016, I additionally reviewed recently published articles from January 2017 to June 2020 to see whether new studies show the same frequently-mentioned TBL dimensions and proximity manufacturing benefits as the previous SLR. I searched for recent articles with the same search terms as before, but only from the Scopus database, as the previous search in 2016 showed that most WoS research results are redundant with the Scopus results. 78 journal articles in English appeared as search hits, excluding review articles. After reading their titles and abstracts and excluding our own published article from Study 2 (Sirilertsuwan, Hjelmgren, & Ekwall, 2019), 39 potential primary studies are selected to be read in details with the content analysis technique. Finally, 31 primary studies presented benefits of proximity manufacturing as shown in Table 2.3.

Table 2.3 Chronological list of the additional 31 primary studies from the updated systematic literature review.

	Primary study		Primary study
46	McEwan (2017)	62	Iyiola et al. (2018)
47	Rothenberg and Matthews (2017)	63	Larsson (2018)
48	Yujin (2017)	64	Hirscher, Mazzarella, and Fuad-Luke (2019)
49	Catterall (2017)	65	Clarke-Sather and Cobb (2019)
50	Bye and Erickson (2017)	66	Garcia, Cordeiro, Nääs, and Costa Neto (2019)
51	Blissick, Dickson, Silverman, and Cao (2017)	67	Trejo, Smith, Trejo, and Lewis (2019)
52	Adikorley, Thoney-Barletta, Joines, and Rothenberg (2017)	68	RÄisÄnen (2019)
53	Truett and Truett (2017)	69	Fontana and Egels-Zandén (2019)
54	Phadnis and Fine (2017)	70	Haque, Khandaker, Chakraborty, and Khan (2020)
55	Štefko and Steffek (2018)	71	Whitfield, Staritz, Melese, and Azizi (2020)
56	Bloomfield and Borstrock (2018)	72	Janssens and Lavanga (2020)
57	Nguyen and Wu (2018)	73	Alexander (2020)
58	Moore, Rothenberg, and Moser (2018)	74	Shih and Agrafiotis (2020)
59	Pal, Harper, and Vellesalu (2018)	75	Shirvanimoghaddam, Motamed, Ramakrishna, and Naebe (2020)
60	Goyal, Singh, Kaur, and Singh (2018)	76	Das et al. (2020)
61	Xie, Dai, Xie, and Hong (2018)		

The results from the 31 primary studies are not used in conducting subsequent studies, but instead for comparing and discussing with the results of the first SLR and the other studies in the last chapter. Including results from other recent studies helps enhance validity and relevancy of the thesis findings.

2.3 Study 2 Semi-Structured Interviews

The results of the previous study (Study 1) enhance proximity manufacturing knowledge relating to TBL in various location contexts; its results in terms of four inductive business aspects and research methods are used in this study. Though existing studies in Chapter 1.3 and Study 1 show various positive and negative factors influencing manufacturing location decisions, the factors changed over time and among different regions (Ellram et al., 2013). Therefore, it is necessary to update current factors of manufacturing location decisions from practitioners. Two research questions help guide this study research.

RQ 5: Why and in which business contexts do managers choose proximity manufacturing over distant manufacturing?

RQ 6: Why and in which business contexts do managers choose distant manufacturing over proximity manufacturing?

RQ 5 and RQ 6 help understand reasons for manufacturing location decisions as well as reveal current positive and negative factors (benefits and barriers) of proximity and distant manufacturing location decisions under TBL. Common and contrasting factors and business contexts among the studied companies are revealed. These help answer RQ 1 and RQ 2. The business contexts can involve company strategies, goals, product types, resources and capabilities, as well as external business environments and stakeholders.

In this study, I adopted the interview-based qualitative approach by following the qualitative research methods of R. K. Yin (2003) and Miles (1994) to ensure research rigor and validity. Initial coding scheme as well as data collection, coding, and analyses are based on Study 1, especially the four inductive business aspects, Chapter 1.2 (TBL concept and sustainable practices), Chapter 1.3 (factors for manufacturing location decisions) and both RQs. I used semi-structured interviews for data collection, the technique of direct content analysis for data coding (Hsieh & Shannon, 2005) and within-case and cross-case analyses for data analysis (Miles, 1994). I interviewed key managers of 12 Swedish clothing brands to explore updated TBL factors of proximity and distant manufacturing and to see whether the factors are different from those found in existing studies.

2.3.1 Company Selection

I chose various types of clothing companies to provide different views, reveal common results for the clothing industry from various company types, and enhance the possibility for generalization of the results within the clothing industry and across industries whose products have similar characteristics to those of the sampled companies.

I utilized theoretical sampling (Eisenhardt, 1989) to select companies who possibly provide factors relating to RQ 5 and RQ 6 to fill in the predetermined coding categories consisting of TBL and the four business aspects. I first started with fashion-oriented companies who have both fashion and basic products that require both proximity and distant manufacturing. According to existing literature, fashion products are manufactured in proximity to markets to respond to uncertain demand. After that I added the other companies selling similar fashion products and different product types until I acquired common factors among most respondents and few new factors which imply its saturation (Guest, Bunce, & Johnson, 2006). The selection method is similar to grounded theory. Ultimately, I decided on 12 Swedish companies comprising of four fashion womenswear, one jean, two menswear, three functional sportswear, and two functional workwear. Further details of the companies can be found in the Sirilertsuwan et al. (2019) study which I published with my supervisors in a peer-reviewed journal.

I chose to interview Swedish companies because they can be good representatives for companies operating in high-cost countries, despite the labor-intensive nature of the clothing industry. I also see the potential of Swedish companies to provide reasons of different manufacturing decisions based on environmental and socio-economic benefits. Moreover, all companies have headquarters in Sweden and main markets in Europe. These are control variables for cultural and communication issues between headquarters and suppliers or markets.

2.3.2 Interview Protocol and Data Collection

Firstly, I contacted and emailed an interview-question guideline to potential participants who are involved in decisions on where to source or manufacture products in the selected companies. Most interviewees were from the direct-contacted informants, with a few interviewees were referred or invited by the informants to join interviews.

I employed semi-structure interview as a protocol because it allows follow-up questions on interesting aspects during the interviews, unclear answers, as well as TBL dimensions and business aspects which were not mentioned by the interviewees. Semi-structured interviews help explore reasons behind the answered factors by respondents leading to the understanding of manufacturing location factors in different business contexts.

During the interview, I focused on asking questions starting with why and how. For example, why do you choose proximity/distant manufacturing? How do you choose suppliers in proximity/distant manufacturing? The questions help reveal not only benefits of proximity and distant manufacturing but also business contexts and operations such as strategies, resources, and capabilities, as well as external environments and stakeholders influencing the manufacturing decisions. The interviews were conducted from April to November 2017 at company headquarters for 60-120 minutes per company. I recorded all 12 interviews and transcribed the recorded interviews which were sent back to the interviewees for information verification (R. K. Yin, 2003).

For additional data and data triangulation, besides interviews, I visited FAS1 and FAS2 retailed shops, a small unit of MEN1 in-house manufacturing, and FXN1 and FXN2 product showrooms. I collected secondary data from company websites before and after the interviews to see their online shops for products and their prices, sustainability reports, sustainability practices, company visions, manufacturing locations, and financial reports. I also obtained some documents from the participants. The triangulated data helped enhance the internal validity of this study.

2.3.3 Data Coding and Analysis

I adopt within-case and cross-case analysis with matrix tables (Miles, 1994) to reveal relationships and emerging patterns of data from all twelve companies. Starting from within-case analysis, I coded data by direct content analysis technique (Hsieh & Shannon, 2005) from each company's transcript, field notes from visiting shops and showrooms, documents, and online data. There are three coding scheme tables for each company: 1) business contexts; 2) positive factors (benefits) of proximity manufacturing and negative factors (barriers) to distant manufacturing; and 3) positive factors (benefits) of distant manufacturing and negative factors (barriers) to proximity manufacturing. I used iterative reading and coding among the data from twelve companies because when there are new benefits from coding a new company, I searched for the new benefits in the data of the previously coded companies. New factors and business contexts were put in a new row and similar ones were put next to one another. The within-case analysis helps not only reveal the factors within business contexts of individual companies, but also helps reduce the amount of data to be analyzed (Miles, 1994).

After that, I applied cross-case analysis to find common and different factors among companies with similar and different business contexts, as well as to reveal emerging patterns of results across 12 company data. Cross-case analysis contains three common tables to gather coded data from all companies. Each table consists of 12 columns of companies and several rows for factors and business contexts from within-case coded data. The rows are categorized by TBL and four business aspects. When reading each table of each company, I marked X at the columns of companies who mentioned the same factor and business context in that row.

2.4 Study 3 Supply Chain Simulations with Objective Measurement

The interview results from the previous study (Study 2) raised many interesting points, which inspired this study to simulate and compare different supply chains with objective measurement, aiding to answer RQ 1 as well as to formulate a model for selecting sustainable multi-tier supply locations leading to answer RQ 2. For example, some companies choose to locate manufacturing in proximity to suppliers in Asia, rather than to market in Europe, because it is more economical to ship garments rather than fabrics due to their sizes affecting transportation costs. On the other hand, some companies prefer vertical suppliers regardless of proximity and distant locations. One study participant who has main markets in Europe and US considered whether it was worthwhile to have an additional manufacturing locations in the US to avoid high import duty fees from current proximity manufacturing to the European market. One manager raised the question of whether shipping garments from Asia by ship emits less carbon dioxide than from Europe by truck. These points from Study 2, together with RQ 1 and RQ 2, lead to two of the research questions of this study.

RQ 7: Which manufacturing location decisions make low cost and/or CO2e supply chains for different markets and computational scope? Based on Weber (1929), manufacturing location decisions include proximity to market, proximity to material source (supplier), and agglomerated supply chain in one location (co-location). However, I propose another manufacturing location decision which is to locate manufacturing in proximity to headquarters, as Study 2 reveals that the short travel time for managers to visit factories is an important benefit of proximity manufacturing to enhance TBL.

RQ 8: What are cost and CO2e factors highly influencing the lowest cost and CO2e supply chains?

RQ 7 helps design supply locations for each market and computational scope of cost and CO2e criteria, while RQ 8 helps realize important factors and possible disruptive risks in order to design and choose a robust supply chain as well as to be careful when collecting data of sensitive factors. Both RQ 7 and RQ 8 help answer RQ 1 and RQ 2.

To answer RQ 7 and RQ 8, I need to calculate and compare cost and CO2e of different supply chains as well as to analyze their factors. To see the effects of proximity and agglomeration among different types of supply chains, it is necessary to control for certain variables which are independent of distances and locations. Therefore, I created supply chain simulations for imitating different types of supply chains. Supply chain simulation and modelling has potential to show the impact of different manufacturing decisions, especially for complex multi-tier supply chains (Mena et al., 2013).

2.4.1 Model Formulation

I searched for studies and models that could potentially help me to simulate different supply chain types to answer the research questions; however, there was no one comprehensive model and study which is capable of producing answers for all of the research questions. Therefore, I adopted knowledge from existing models and studies to formulate a model with the potential to answer RQ 7 and RQ 8. The proposed model shows steps on how to calculate, compare, and analyze different supply chains to enhance TBL.

Existing models and studies help formulate my proposed model in terms of objective measurement criteria, activities and factors to be included in cost and carbon emission calculation, and deciding what is to be analyzed as shown in Table 2.4. I aim to create a model for sustainable multi-tier supply location decisions to reveal answers to the research questions by adopting simulation and modelling approaches which have been the tools for many studies on complex and multi-tier supply chains (Mena et al., 2013). During development of the model, I focused on pragmatic validity and practical relevance to ensure that the model is capable of producing intended outcomes and of being used in other applications beyond one specific domain (Oliva, 2019).

The model adapted the industrial location theory of Weber (1929) into multinational manufacturing locations with the integration of sustainability perspectives in order to fulfill the theoretical gap mentioned in Chapter 1.5. I use cost and CO2e as proxies to measure and compare business and environmental performance of different supply chain alternatives. Cost and carbon emissions have been widely used in supply network design research with sustainability focus (Chaabane et al., 2010; Mishra & Singh, 2019; Ramudhin et al., 2010; Teimoury et al., 2017). Therefore, cost and CO2e are measurement criteria for the proposed model.

Table 2.4 How the proposed model is formulated based on various studies.

Key takeaways for developing the proposed model	Inspirations from these studies
Objective measurement for different manufacturing locations to serve more than one main markets	Study 2[a]
Multi-tier focus; to include more than final product (1st – tier) suppliers	Study 2[b]
Application of the model for either new supply chain design or existing supply chain evaluation	Study 2[c]
Carbon dioxide (CO_2) or greenhouse gas (GHG) emissions as environmental measurement criterion	Chaabane et al. (2010); Mishra and Singh (2019); Nouira et al. (2016); Ramudhin et al. (2010); Teimoury et al. (2017)
Cost and CO_2 or GHG emissions as measurement criteria	T.-C. Kuo et al. (2018); C. T. Kuo and Lee (2019)
Including logistics activities especially transportation mode and distance	Study 2[d], Nouira et al. (2016), C. T. Kuo and Lee (2019)
Including sustainability assurance activities at factories and by focal firms	Study 2[e], Chapter 1.2 (reviewing sustainable practices)
Considering locations of recycled/remanufactured factories	Study 2[f], Chapter 1.2 (reviewing sustainable practices)
Including factors relating all forms of inputs and outputs such as gas, solid, liquid, and energy	Chaabane et al. (2010)
Calculating emissions from electricity consumption and power consumption in manufacturing stages; and considering material quantities and production capacity	T.-C. Kuo et al. (2018); C. T. Kuo and Lee (2019)
Calculating emissions from different production technology and transportation	Ramudhin et al. (2010); Nouira et al. (2016)
Observed outcomes on proximity and agglomeration between locations of supply chain stages	Study 2[g], Weber (1929), Brush et al. (1999)
Exploratory data analysis	Seltman (2018)
Analysis by Pareto fronts	Lotov (2004); Perez Loaiza et al. (2017)
Analysis by scenario-based technique	Wright, Bradfield, and Cairns (2013); Perez Loaiza et al. (2017); Srinivasan and Khan (2018)
Sensitivity analysis	Triantaphyllou and Sánchez (1997)

Remarks: [a] A company does not know whether it is worth to have proximity manufacturing to its north American market in addition to current proximity manufacturing to its European market; [b] Most companies have nominated materials suppliers and/or materials specifications for final product suppliers to source from; [c] A company is hesitated to have a new supply chain for another main market outside Europe and some companies periodically evaluate their suppliers' performance yearly; [d] A manager mentioned that delivery products by ship from distant manufacturing could be more environmentally-friendly than by truck from proximity manufacturing; [e] Interviewed participants mentioned about factory having certificates and/or meeting code of conduct; and managers from headquarters flew to visit factories; [f] Some companies have recycled program; and [g] Managers mentioned benefits from proximity manufacturing to both suppliers and markets.

I adopted logic models (Clark & Anderson, 2004; Millar, Simeone, & Carnevale, 2001) as a tool to identify inputs and outputs of activities as well as intermediate and long-term outcomes, namely TBL sustainability. With a focus on achieving TBL sustainability, logic models help realize the importance of including sustainability assurance activities performed by suppliers and focal firms into the manufacturing location decision model. The sustainability assurance activities mentioned are from Study 2 and Chapter 1.2 on reviewing sustainable practices. As a result, besides traditional cost and CO2e calculations from logistics and manufacturing activities, I include cost and CO2e from sustainability assurance activities performed by suppliers and focal firms into the proposed model.

The sustainability assurance activities performed by suppliers included into my proposed model for assuring environmental and socio-economic sustainability at factories are waste treatment, living wage payments, and social security contribution. Waste can be in any form of gas, solid, or liquid. Sustainability assurance activities performed by the suppliers for assuring product quality and environmental and socio-economic sustainability relate to sending samples for lab tests for chemicals and headquarters approval for quality and specifications, as well as implementing and acquiring sustainability-related certificates including employee training and reporting. In the proposed model, I included all of these sustainability assurance activities performed by suppliers into traditional cost and CO2e computations, hereafter referred to as the landed cost/CO2e computational scope, or “the landed scope.”

Sustainability assurance activities can be performed by focal firms through factory visits, as mentioned by managers in Study 2. The model takes into account cost and CO2e from the travelling of managers and costs of hotels and managers during factor visits. The computational scope, which includes sustainability assurance activities performed by focal firms in addition to the landed scope, hereafter is referred to as the firm cost/CO2e computational scope, or “the firm scope”. The sustainability assurance activities differentiate the proposed model from existing cost and environmental models for manufacturing location decisions, which do not include cost and carbon emissions from sustainability-related activities, as shown in the State-of-the art review in Chapter 1.4. For a closed-loop supply chain, the computational scope can be extended to consider cost and CO2e from reverse logistics for sending used products to recycling facilities, hereafter referred to as the reverse-logistic cost/CO2e computational scope, or “the reverse-logistic scope.”

For designing new product supply chains, this proposed model helps users to calculate costs that should be quoted by suppliers to meet sustainability compliances. A few managers from Study 2 mentioned that they were skeptical to quoted prices by suppliers that were very low, as they worried about poor quality and inability to meet environmental and social compliance. Therefore, it is necessary to know estimated prices.

I use the activity-based costing (ABC) technique to allocate indirect cost and CO2e into produced units. ABC also helps reveal activities relating to produced products, aiding the identification of factors to be calculated for supply chain costs and CO2e. ABC has been widely used in supply chain studies relating decision support on profitability including cost, process, productivity, and organization performance (Askarany, Yazdifar, & Askary, 2010).

Iterative processes between the model formulation and application ensure the pragmatic validity of the model to produce the intended outcomes for RQ. After I applied the first few versions of the model with different types of viscose t-shirt supply chains, I found that it was necessary to add more steps and reorganize the steps into the model to help users design a sustainable product supply chain. The lists of factors for cost and CO2e calculation have also been improved by feedback from other researchers, revising business and supply chain operations from the interviewed transcripts in Study 2, and my over ten-year experience in business management, product sourcing, and international trade.

2.4.2 Model Application

Due to the lack of collaboration with a company for the model application, I set a scenario that a focal firm is looking for manufacturing locations for viscose t-shirts. I chose to apply the proposed model to viscose t-shirt supply chains because t-shirts are basic garments which can be repeatedly produced due to continuous demand and viscose fibers have potential to be produced with clean technology around the world, unlike cotton, which is limited to certain countries and consumes a lot of water. The potential to be produced around the world helps generate various supply chains to be analyzed, such as agglomerated proximity manufacturing, dispersed proximity manufacturing, agglomerated distant manufacturing, and dispersed distant manufacturing to markets.

In this model application, the focal firm is assumed to be a European retailer who has its headquarters and warehouse in Germany (DE) which is the main market of the clothing industry for Europe (https://www.statista.com/topics/3423/clothing-and-apparel-market-in-europe/). According to the interviews with managers in Chapter 3, all finished garments are delivered to their main warehouses, located near their headquarters, before being distributed to different markets both inside and outside Europe. In this case, market locations do not influence the design of supply locations. Therefore, the model application initially simulated three-tier supply chains by varying fiber, fabric, and garment manufacturing locations for the warehouse in Germany. For future markets, I extended the analysis to include directly sending finished garments from respective factories to each market warehouse in Germany (DE), the United States (US), and China (CN) to see the potential of the model and whether different markets have common costs and CO2e efficient supply locations or not. Therefore, the model application simulated four-tier supply chains.

3 Results and Analysis

3.1 Study 1 Systematic Literature Review on Proximity-Manufacturing Benefits

I report two sets of SLR results. The first set is from the 45 primary studies which are published up to 2016. Its findings are used in Study 2 and Study 3 and published as a journal paper (Sirilertsuwan et al., 2018). The other set of results is from the 31 primary studies published during 2017 and June 2020. Its results help update knowledge and trends relating to proximity manufacturing to be compared with the thesis findings from Study 1-3.

3.1.1 Analysis on Trends and Absences of the 45 Primary Studies

This section presents results, analysis, and discussion about artifacts of the primary studies (methods, locations of studied context, and TBL dimensions) for answering RQ 4. In order to ensure that the results and analysis are not biased towards certain perspectives, I firstly checked author and journal distribution of the primary studies. The distribution of authors and journals show good variation with 83 authors and 38 journals for the 45 primary studies.

3.1.1.1 Methods and Data Sources Across Time

The 45 primary studies used various methods and data collection as shown in Figure 3.1. Most articles use the qualitative approach followed by the quantitative approach and the mixed method approach. All three articles published before 2000 use the qualitative approach. The numbers of other qualitative studies published before (eleven articles) and after 2010 (eleven articles) are almost equal. On the other hand, the number of the quantitative studies published after 2010 (13 articles) is more than the one after 2010 (four articles). The results show the increasing trend of using quantitative approach and the stable trend of using qualitative approach. Mixed method still under represented with only two articles each before and after 2010.

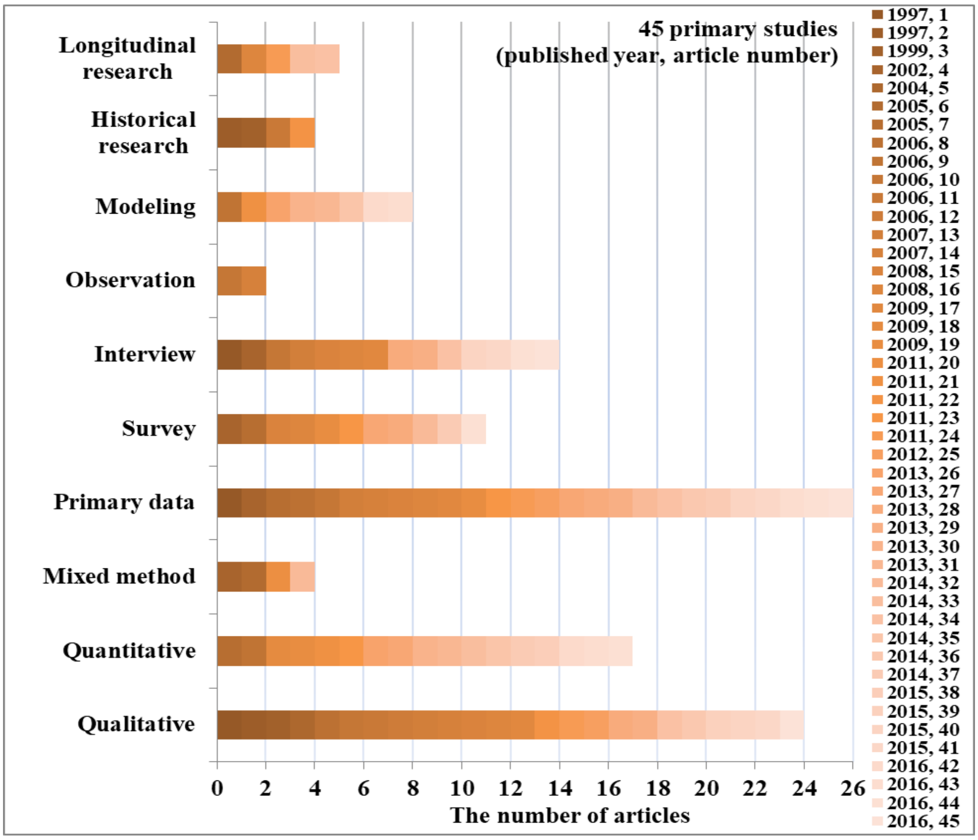

Figure 3.1 The number of articles out of the 45 primary studies adopted different methods and data sources across time.

Remarks: Chronological results from dark color to light color indicate old to recent published articles; the article number links to the studies shown in Table 2.2.

Regarding data sources, 17 of 24 qualitative studies have primary data collection mainly by interviews or semi-structured interviews, few by both survey and interviews, and only one by observation. Two of the four mix-method studies collected primary data with survey and both survey and interview. Only seven of 17 quantitative articles had the primary data collection mainly with survey excepting one article with both survey and interview. Moreover, eight of the qualitative studies are modelling while four of the qualitative studies are historical research without primary data collection. Three qualitative studies, one quantitative study, and one mix-method study are longitudinal research. The results demonstrate that qualitative studies tend to use interviews for primary data collection and most longitudinal research has adopted the approach and tool. Contrary, the quantitative studies tend to collect primary data by survey or use modelling without primary data collection.

3.1.1.2 Studied Context Locations Across Time

Investigating the studied context in terms of production and market locations helps realize whether extracted factors of proximity manufacturing get more influenced by certain regions. Moreover, common and different factors of proximity manufacturing among different locations can be revealed during the content analysis of the factor in the section 2.4. Figure 3.2 presents that the majority of the 45 primary studies focus on the European market (14 articles) and the American market (12 articles) followed by the Asian market (8 articles). On the other hand, proximity manufacturing studies relating to African and Oceanian markets are few and outdated showing the unfulfilled research. Furthermore, Figure 3.2 shows the chronological lists of primary studies under different locations. It reveals the trend of newly studies published after the year 2013 on European market, Asian market, North American market, and unspecified global markets which include any high and low cost countries around the world.

The results of reviewing studied markets show that most studies mentioned production locations in the market locations and/or nearby the market locations. It can be seen that

European markets mainly have proximity manufacturing in the Eastern and Southern Europe. American markets mainly have proximity manufacturing in Mexico. Asian markets mainly have proximity manufacturing in their own countries and China is the most-mentioned Asian market and production locations. The results reveal that proximity manufacturing to low-cost markets refers to domestic manufacturing while proximity to high-cost markets refer to nearshoring manufacturing to lower-cost countries nearby the market locations. Data regarding to production and market locations can be found in Sirilertsuwan et al. (2018).

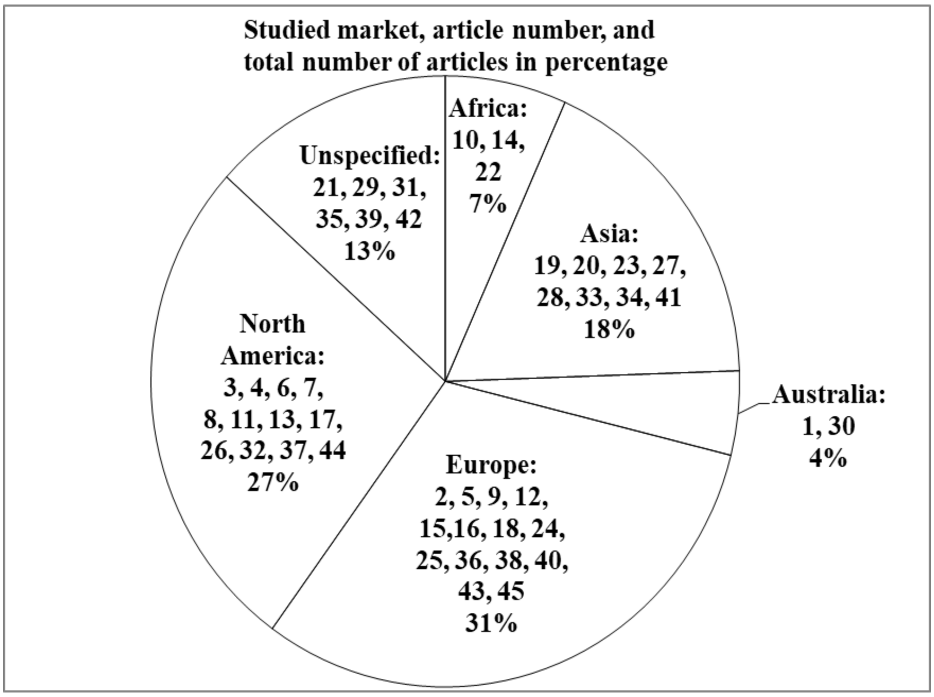

Figure 3.2 Primary studies in each studied context based on market locations.

Remark: the article number links to the studies shown in Table 2.2.

3.1.1.3 TBL Dimensions Across Time

Regarding how proximity manufacturing studies relating to TBL sustainability, most of the 45 primary studies focus on business dimension and environmental dimension is lack of their attention. There are one study with environmental dimension, seven studies with business and environmental dimensions, one study with environmental and social/socio-economic dimensions, and three studies with all TBL. Moreover, all TBL have started to be in focus since 2014. Surprisingly, there is high number of studies mentioned socio-economic benefits of proximity manufacturing but only with business and/or environmental dimensions. 22 studies mentioned the social/socio-economic benefits together with the business benefits across the time period with two and three published studies per year during 2006-2009 and 2013-2015. More information on which primary studies mentioned which TBL benefits are shown in Figure A.1 in Appendix A.

3.1.2 Content Analysis for TBL Proximity Benefits of the 45 Primary Studies

This section presents extracted benefits of proximity manufacturing under each TBL in each studied market location for answering RQ 3.

3.1.2.1 Four Inductive Subgroups in the Business Dimension

During extracting benefits of proximity manufacturing from the 45 primary studies, there was high number of benefits under the business dimension leading to the categorization of the factors. Placing similar benefits next to one another during the extraction reveals groups of factors. The inductive subgroups were from categorizing the groups of factors that are correlated and have relationship to one another. Finally, four subgroups under the business dimension are profits relating to costs, price, and sales; service and delivery relating to what help deliver products and services to customers; product and manufacturing/operations process development and innovation; and product quality.

The content analysis of the 45 primary studies shows 222 proximity-manufacturing benefits under TBL: 182 under the business dimension, 18 under the environmental dimension, and 22 under the socio-economic dimension. The numbers of benefits in the four business subgroups are 72, 72, 25, and 13, respectively.

Within the 45 primary studies, 43 studies mentioned business-related benefits and 12 and 36 studies mentioned the environmental and social/socio-economic benefits, respectively. The numbers of studies mentioned business subgroups are 39 for profits, 35 for service and delivery, 27 for product/process development, and 18 for product quality. High numbers of studies mentioned the profit and service and delivery benefits of business while the product/process development and product quality benefits of proximity manufacturing seem to be underdeveloped. There is a lack of studies focusing on all TBL and/or all business subgroups as by only three articles mentioned all TBL benefits (Jung & Jin, 2014; Sardar et al., 2016; Zhu & Pickles, 2014) and only one article mentioned all TBL benefits with all business subgroups (Zhu & Pickles, 2014). Detailed information on how each primary study involves in each TBL and business subgroups are in Figure A.1 in Appendix A.

3.1.2.2 Important Proximity Benefits Across Time and Locations under TBL

Important benefits of proximity manufacturing under each TBL are extracted from frequently-mentioned benefits by the primary studies. I analyze the benefits across time periods in each studied-market location in order to see the benefit evolution in each continent and the common and different benefits among the continents. The important proximity-manufacturing benefits highly-mentioned by primary studies across studied markets and time periods under TBL and the four business subgroups are shown in Figure A.2 in Appendix A while Figure 3.3 focuses on presenting differences of proximity-manufacturing benefits among all studied markets.

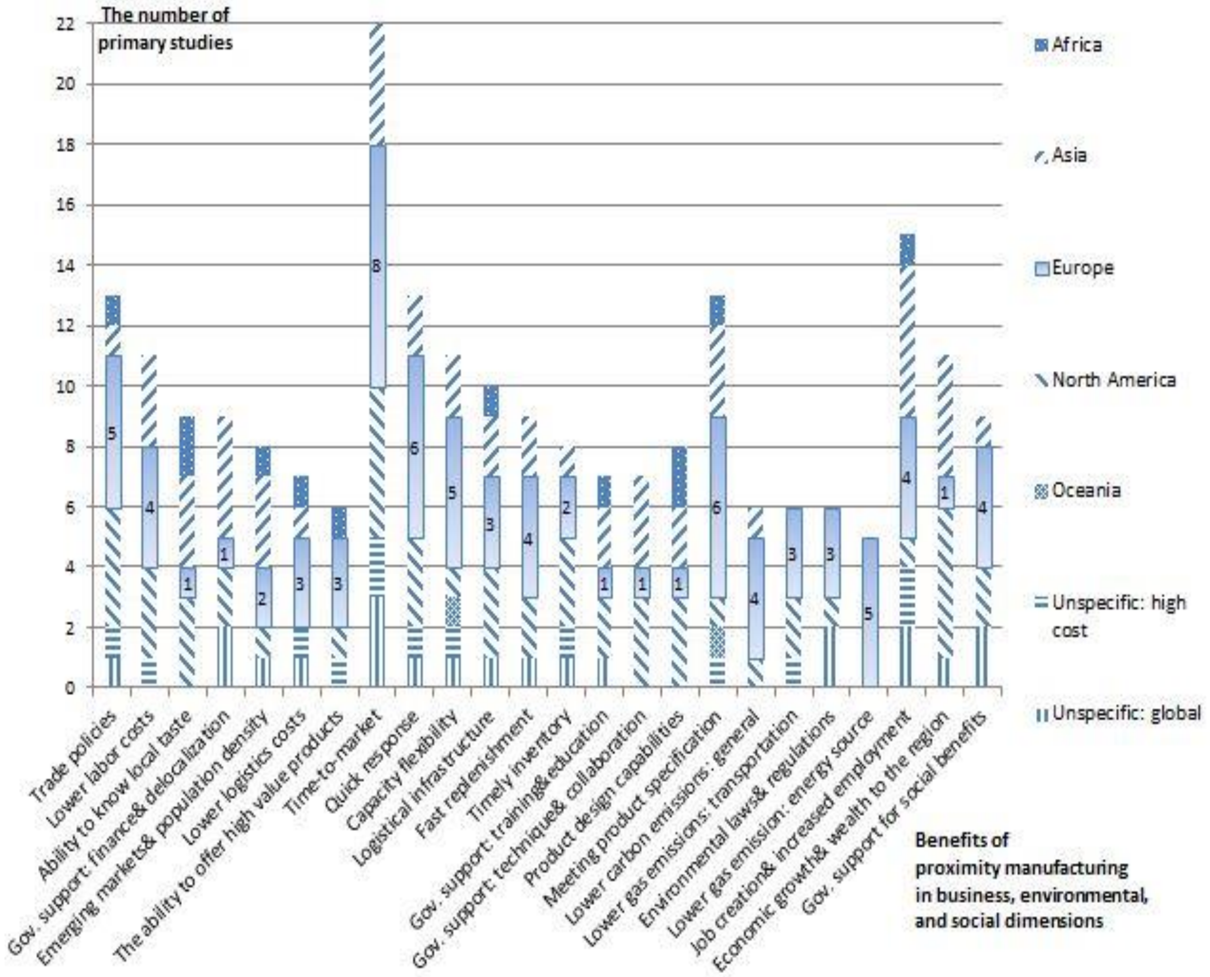

Figure 3.3 Frequently-mentioned benefits by the 45 primary studies under each studied market.

Remarks: European-market studies are dominant and indicated with the number of primary studies mentioned each benefit; and Gov. support refers to governmental support.

Within the business dimension, there are a lot of mentioned benefits under profits and service and delivery subgroups rather than the product/process development and product quality subgroups. However, the product quality is the top-three highly-mentioned benefits together with trade policies and quick response after time-to-market and job creation.

Under the profit subgroup, trade policies seem to be important for the proximity manufacturing to Europe and North America while abilities to know local trends and tastes as well as financial support from government seem to be important to Asia proximity manufacturing. Proximity-manufacturing benefits from lower logistics costs and abilities to offer high-value products seem to be important benefits to proximity manufacturing to Europe. Most studies of all continents excepting Africa and Oceania show the importance of proximity manufacturing to their location in terms of service and delivery especially time-to-market. The service and delivery benefits especially quick response, capacity flexibility, and fast replenishment have been more important to European market than the others. Nevertheless, there seems to be an increasing trend of the service and delivery benefits for Asian proximity manufacturing. Figure 3.3 also shows that the benefits in the product/process development business subgroup have been important for Asian and North American proximity manufacturing rather than European proximity manufacturing. Surprisingly, the benefit regarding high product quality is highly important to European proximity manufacturing followed by Asian proximity manufacturing rather than North-American one. This implies that Asia proximity manufacturing can offer high quality product besides being lower-cost locations.

In Figure 3.3, the socio-economic benefits seem to be important to proximity manufacturing to the Asian and North American markets while the environmental benefits seems to be important to proximity manufacturing to the European market. However, the Asian market lacks governmental support on social compliances and benefits unlike the European market. Moreover, government can influence several benefits under all TBL and almost all of the four business subgroups by directly supporting tax rebate, finance, delocalization, education and training of labors, production techniques, business collaboration, production clustering, as well as environmental- and social-related laws and regulations. In addition, governments potentially support proximity manufacturing through efficient and low cost logistics infrastructure as well as trade policies.

Regarding the published articles from 2013 to 2016, all unspecified global-location studies are recent and most of their highly-mentioned benefits relating to profits and service and delivery business subgroups as well as the social/socio-economic dimension. On the other hand, African- and Oceanian-market studies are outdated leading to the call for attention. Furthermore, there seems to be the decreasing studies on European and American markets and the increasing studies on Asian market after 2013. The environmental and social benefits have been mentioned by recent studies on every market excepting African- and Oceanian markets. Under the business dimension, recent studies on Asian market present a good distribution of benefits among the four business subgroups rather than recent studies on European and North American markets whose benefits are concentrated in the service and delivery subgroup and/or the profit subgroup. Moreover, recent North American-market studies have less focused on the profits and product/process development subgroups and more focused on the service and delivery subgroup than before the year 2013.

3.1.3 Updated TBL Proximity Benefits from the 31 Primary Studies

This additional SLR on recent published articles during 2017 until the present (the end of June 2020) shows a significant increase of studies considering all TBL benefits of proximity manufacturing as shown in Table 3.1. Table 3.1 shows the number of primary studies from both SLRs published in each year and how they relate to TBL. Table 3.1 reveals that some recent studies from the additional SLR focus on only the socio-economic dimension which was not the case for the previous SLR. Though the environmental dimension seems to be hardly mentioned, the additional SLR shows the trend of sustainable production and consumption through slow fashion and circular economy concepts (49, 50, 55, 56, 59, 63, 64, 67, 68, 74, 75). The number in parenthesis in this section refers to article numbers in Table 2.2 and Table 2.3 showing primary studies of both SLR.

Table 3.1 The number of studies from both literature reviews published in each year and mentioned business, environmental, and socio-economic benefits of proximity manufacturing

Year	Business	Environment	Society	Business and environment	Business and society	Environment and society	Business, environment, and society	Total number of studies
1997	1	0	0	0	1	0	0	**2**
1999	1	0	0	0	0	0	0	**1**
2002	0	0	0	0	1	0	0	**1**
2004	0	0	0	0	1	0	0	**1**
2005	2	0	0	0	0	0	0	**2**
2006	1	1	0	0	3	0	0	**5**
2007	0	0	0	0	2	0	0	**2**
2008	0	0	0	0	2	0	0	**2**
2009	0	0	0	0	2	1	0	**3**
2011	4	0	0	0	1	0	0	**5**
2012	0	0	0	1	0	0	0	**1**
2013	1	0	0	1	3	0	0	**5**
2014	0	0	0	3	2	0	2	**7**
2015	0	0	0	1	3	0	0	**4**
2016	1	0	0	1	1	0	1	**4**
2017	2	0	0	0	3	0	4	**9**
2018	0	1	1	0	2	1	4	**9**
2019	0	0	2	0	0	0	4	**6**
06/2020	1	0	1	0	1	2	2	**7**
Total number of studies	**14**	**2**	**4**	**7**	**28**	**4**	**17**	**76**

The additional SLR also shows that consumers are willingness to pay more for local products for gaining high-quality and/or differentiated products and supporting local businesses (46, 47, 48, 50, 59, 65, 67, 68, 74). This is the most-mentioned benefit by the recent studies under the profit business subgroup. The most-mentioned benefits by the recent studies under the other business subgroups are similar to the benefits revealed by the previous SLR as shown in Table 3.2.

Table 3.2 Updated studies mentioned TBL benefits from Sirilertsuwan et al. (2018).

TBL	Most frequently-mentioned benefits	AF (6)	AS (14)	OC (4)	EU (22)	NA (19)	HC (4)	U (6)	SA (1)
Profits (cost-price-sales)	Trade policies (16)	22	41	**46, 53**	5, 12, 15, 40, 45	6, 8, 13, 17, **52**	21	39	
	Lower labor costs (12): domestic or nearshoring		20, 33, 34		5, 15, 24, 45	11, 17, 44, **52**	42		
	Knowing local taste and trends (10)	10, 22	20, 28, 41		16	3, 11, 13, **50**			
	Governmental support: tax, finance, and delocalization (12)	**71**	19, 28, 34, 41	**53**	15	13, 17, **55**		29, 39	66
	Emerging markets and population density (10)	22	19, 28, 34, **60**		24, 45	17	**58**	39	
	Lower logistics costs (8)	22	34		15, 38, 43	52	42	39	
	The ability to offer high value products (11)	10			15, 16, 40, **68, 74**	13, **50**	21, **54, 58**		
Service and delivery	Time-to-market (27)		19, 33, 34, 41		12, 15, 16, 24, 36, 38, 40, 45, **56, 59**	6, 7, 8, 13, 44, **52**	21, 42, **54, 58**	31, 35, 39	
	Quick response (16)		33, 41		2, 12, 15, 24, 36, 40, **59**	6, 26, 44, **50**	42, **54**	39	
	Capacity flexibility (15)		19, 41	1	2, 15, 16, 40, 45, **56, 59**	13, **50**	42, **54**	39	
	Logistical infrastructure (11)	22	19, 33		36, 38, 40	3, 8, 26	**58**	35	
	Fast replenishment and timely inventory (13)		34, 41		12, 15, 24, 36	6, 7, 13, 26	21	35, 39	
Product or process development	Governmental/external support: training and education (13)	10, **71**	34, 41, **51**	**53**	16	4, 17, **50, 55, 65**		29	
	Governmental/external support: production technique, clusters, and business collaboration (15)	**71**	19, 27, 34, **48, 51**	**53**	16, **74**	4, 11, 17, **49, 50, 55**			
	Product design capabilities: customization and high-value addition (12)	10, 14, **71**	19, 33		16, **68**	4, 13, 44, **49, 50**			
Product quality	Meeting product specification and high product quality (21)	10	20, 34, 41	1, **46**	5, 15, 16, 24, 36, 40, **59, 68, 74**	44, **47, 50, 52**	42, **58**		
Environ-ment	Lower carbon emissions (6)		34		18, 25, 38, 43	26			
	Lower gas emissions from transportation (8)				25, 38, 43	26, 32, **65**	42	**76**	
	Governmental support: environmental regulations (8)		**61**		9, 38, 43	26, **50**		31, 35	
	Lower gas emissions from clean energy source and technology (6)				9, 18, 25, 38, 43	**65**			
Society	Job creation and increased employment (24)	10, **51**	19, 27, 28, 33, 34, **57**	**46, 53**	2, 15, 40, 45, **68, 74,**	8, **50**	21, 42	29, 39, **75, 76**	
	Economic growth and wealth to the region (24)	**62**	19, 27, 33, 34, **48, 57, 69, 70**		45, **56, 64**	8, 13, 17, 32, 37, **50, 55, 65, 67**		29, **76**	**66**
	Governmental support: social benefits and compliances (10)		34		2, 15, 18, 45	4, 11, **50**		29, 39	

Remarks: 2017-2020 studies in bold; Parentheses denote the number of studies; and AF: Africa, AS: Asia, OC: Oceania, EU: Europe, NA: North America, HC: Any high-cost locations, U: Unspecific, SA: South America.

The consumer willingness was also mentioned in some primary studies in the previous SLR for supporting both local business and environmental sustainability (23, 25, 30, 32, 35, 43). Moreover, proximity manufacturing could lead and gain benefits from consumer awareness on environmental sustainability (30, 43, 50, 55, 73).

Besides Table 3.2, the updated SLR shows benefits relating the profit business subgroup are reducing risks from uncertain markets by better forecasting (26, 31, 50, 52, 54, 58) as well as inventory, transaction, and coordination costs (24, 26, 33, 41, 50, 58, 59). Due to short lead-time, proximity manufacturing gives benefits in postponing/delaying orders in order to ensure demand (13, 21, 31, 54). The other benefits relating the service and delivery business subgroup are abilities to customize production and have diverse products (50, 59, 63) and high efficiency of production and supply chains (58, 59). Efficiency can also gain from integrated supply chains by locating suppliers of different supply chain stages in proximity to one another and in cluster (4, 6, 19, 33, 37, 51).

Under the product quality and product/process development business subgroups, accessing specialized local tailor, craftsmanship, or premium materials and product is highly mentioned in the recent SLR (46, 49, 50, 67, 68, 71, 74) besides the most frequently-mentioned benefits in Table 3.2. Some studies in the previous SLR also mentioned this benefit (6, 16, 22, 28, 33). The ease of controlling supply chains seems to remain overlooked as there are only three recent-reviewed studies (46, 50, 59) mentioned about proximity benefits on the ease of communications, operations, quality, and sustainability control and one previous-reviewed study mentioned about less time and cost to visit factories (44). The other benefits are knowledge spillover and sharing among proximity manufacturing network (49, 59, 64, 71, 76) and business alliances and synergies for competitiveness (46, 51, 57, 71, 74).

Some studies mentioned benefits from cultural, ethnic, and linguistic proximity (50, 51, 71). The older articles from the previous SLR mentioned similar benefits on these points are knowledge spillover and shared technology (19, 29, 33, 41) and accessing social network for business alliance and informal training (4, 16, 17, 27, 29).

Under the socio-economic dimension, the most-mentioned benefit of proximity manufacturing by the additional SLR is to support local input suppliers of the industry (49, 50, 51, 55, 59, 60, 62, 63, 65, 66, 67, 68, 71, 75) and of the other industries such as cereal and chemical industries (70, 76). Only four studies from the previous SLR presented this benefit (13, 27, 29, 37). The second most-mentioned benefit by this additional SLR is the same as the previous SLR most-mentioned benefits as shown in Table 3.2. Besides the benefits in Table 3.2, this additional SLR presents many highly-mentioned benefits by recent studies. The additional SLR reveals that local manufacturing in some countries allows accessing and preserving local skills, craftsmanship, and artisans (46, 48, 49, 50, 60, 64, 67, 68, 71, 74). Only three studies from the previous SLR mentioned the benefit (14, 29, 40). Moreover, the recent SLR demonstrated that local initiatives for supporting local manufacturing potentially lead to social inclusion, interaction, and pride in society (48, 49, 50, 56, 64); and only one study from the previous SLR mentioned this benefit to society (14). The additional SLR presents an additional governmental support relating domestic raw material production aiding industrial retention (51, 60, 70). Regarding social compliances, there are hardly studies mentioned benefits relating working conditions, labor practices, and chemical safety and security at factories (50, 69, 70, 73). Nevertheless, proximity manufacturing may gain the benefit on fair wage payment from the slow fashion concept (50, 55, 74).

For the environmental dimension, using local suppliers and artisans also support local resource utilization (49, 50, 74, 75, 76) and input resources could be from wastes or co-/by-products of other industries (76) help reduce waste emissions. Some proximity-manufacturing locations have abilities to produce sustainable materials enhancing environmental sustainability (49, 51, 59). Another new benefit from geographical proximity is saving energy in transportation (76) besides gas emissions.

3.1.4 Conclusion and Implications

This systematic literature review on proximity manufacturing helps reveal the benefits and potentials of proximity manufacturing to different locations under the business, environmental, and social/socio-economic dimensions of the Triple Bottom Line (TBL) sustainability from the 45 primary studies. Descriptive analysis and content analysis are used to extract information from the 45 primary studies to see the trends of methods used in related studies, studied locations, TBL dimensions, and benefits under all TBL and business subgroups across time and studied markets. Four business subgroups (profits, service and delivery, product/process development, and product quality) were induced during the content analysis due to the high number of business benefits revealing the benefit categories.

Regarding RQ 4, the findings show the lack of proximity manufacturing studies relating to all TBL and to the environment dimension as well as the African and Oceania markets. After the year 2013, there are the increasing trends of studies on European market, North American market, Asian-market, and unspecific global location markets. Regarding the relationship between production and market locations, proximity manufacturing to low cost markets refers to domestic production locations while proximity manufacturing to high cost markets refers to production locations in nearby countries. Furthermore, the qualitative studies with primary data collection by interviews have been common methods and there is an increasing trend of quantitative studies with modelling. Mixed-method studies are still rare.

Regarding RQ 3 for benefits, market locations, and TBL, profit and service and delivery subgroups have had several benefits mentioned by several studies across all studied markets excepting by Oceania-market studies. Time-to-market, quick response, trade policies, and meeting product specifications have been important business benefits for proximity manufacturing to European, Asian, and North-American markets excepting trade policies for Asian market and meeting product specifications for North-American market. Most environmental benefits relate to gas emissions. They seem to be important for the proximity manufacturing to the European market and are undermined in the Asian market. On the other hand, job creation and economic growth as social/socio-economic benefits seem to be important for the proximity manufacturing to the Asian market. However, the Asian market still lacks the governmental support on social compliances and benefits. In addition, government plays an important role in supporting proximity manufacturing to several locations in all TBL and most of the business subgroups.

3.2 Study 2 Semi-Structure Interviews on Proximity- and Distant-Manufacturing Factors

3.2.1 Business Contexts

Company information helps understand business contexts relating to factors of proximity and distant manufacturing decisions. The company information on brand, founded year, number of employees, turnover, product and average retail price, distribution channel, replenishment policy and strategy, and fabric control level are shown in Table 3.3. Company information regarding manufacturing locations and representatives at manufacturing sites can be found in Table 3.4.

Table 3.3 Information of sampled companies showing different business contexts.

Sampled companies	FAS1	FAS2	FAS3	FAS4	DNIM	MEN1	MEN2	FXN1	FXN2	FXN3	WRK1	WRK2
Internal brand	x	x	x	x	x	x		x	x	x	x	x
External brand		x	x	x			x					
Year of founding	1950's	1950's	1940's	2000's	2000's	1920's	2010's	1990's	1970's	1910's	1920's	1950's
Number of employees (* only in headquarter)	4,000+	4,000+	580*	300	80	240	47	23	72*	58*	2,000+	3,200/ 250*
Turnover in 2016/ internal brand (market value), €million	374	353	200/ 140	124/ 50	49	79	14	13	50 (100)	47 (60)	398	96
Product category	Fashion	Fashion	Fashion	Fashion	Denim	Shirt	Outer layer	Sport jacket	Sport inner layer	Sport jacket	Work wear	Work wear
Female	x	x	x	x				x		x		
Male	x					x	x	x		x		
Kids	x	x	x					x				
Trouser	x						x				x	x
Jersey	x	x										
Average retail price (€: < €50, €€: €51-€150, €€€: > €150)	€	€	€	€	€€€	€€€	€€€	€€, €€€	€€	€€	€€	€€
Brick-and-motar store	x	x			x	x		x		x (1)		x
Online	x	x	x	x		x	x	x		x		
Business-to-business sale		x			x	x		x	x	x	x	x
Replenish: Never out of stock percent of assortment			30-40			50	20			30-35		
Replenish: Reordering	x	x		sales	carry over style				50% of turnover		x	sales, carry over style
Advanced fabric preparation	x	From vertical supplier			x	x			From vertical supplier		x	
No replenishment			seasonal product					complex garment				
Fabric development (*provide component)					x	x*						
Nominated specification (*&supplier)	x				x*			x*	x	x*	x*	x

Table 3.4 Manufacturing locations of the sampled companies (x) and their local representatives at manufacturing locations (L) showing business contexts.

	FAS1	FAS2	FAS3	FAS4	DNIM	MEN1	MEN2	FXN1	FXN2	FXN3	WRK1	WRK2
Asia	x, L	x, L	x	x	x			90%	80%	100%	x	100% work-wear
Europe	x	x	x	x	x	x		x	x		x, **<u>x</u>**	x
Africa					x						x	
China	x	x	55%	x				x	x, L	x, L		
Hong Kong		x		L							L	
South Korea	x											
Bangladesh	x	x	8%	x, L					x, L	x		20%
India	x	x	19%	x	x, L			x				
Pakistan		x	1%	1%, L								
Sri Lanka												x
Cambodia		x										
Vietnam		x						x	x, L	x		x
Turkey	x, L	x, L	x	x	x				x		x	
Ukraine	x										x, **<u>x</u>**	
Romania	x					x, L			x			
Lithuania					x	x		x	x		x	x
Estonia						x, L		x				x
Latvia								x			x	x
Slovenia									x			
Italy	x	x			x, L			x				
Portugal	x		x		x, L				x		x	
Belgium			1%									
Sweden	x		1%		x			x	x		x	
United Kingdom				x, L								
Macedonia						x						
Russia											x	
Tunisia					x							
Madagascar											x	
Local representa-tives	6 produc-tion offices	7 produc-tion offices	Agent	Buyer, Agent	Office, agent	One em-ployee, own produc-tion system	N/A	No	Buying offices	Represen-tative office	Purchasing office, own factories	Own facto-ries

Remarks: Bold **x** indicate main manufacturing; and underlined <u>x</u> indicate in-house manufacturing.

Both Table 3.3 and Table 3.4 show different and common business contexts within and among fashion women wear, jean, menswear, sportswear, and workwear businesses. These are later used for analyzing how business contexts influence proximity and distant manufacturing decisions and practices. Moreover, MEN2 sells only external brand clothing and does not engage in manufacturing activities unlike the others who know where garments are manufactured.

3.2.2 Proximity Manufacturing Benefits

Benefits of proximity manufacturing are presented in Figure 3.4. Most benefits mentioned by most managers are benefits of proximity manufacturing to Europe, where markets and headquarters of sampled companies are located. However, some benefits are from garment manufacturing in proximity to fabric manufacturing such as lower duties and logistics costs, risk avoidance, garment-cost structure, short lead-time and travelling time of managers to visit factories for price and style discussion, smooth operations due to similar culture for cooperation as well as lower gas emissions mentioned by five of six managers who mentioned lower gas emissions as an benefit. Moreover, all mentioned benefits by FXN3 are from garment manufacturing in proximity to fabric manufacturing rather than to market/headquarter because all FXN3 manufacturing are located in Asia. Furthermore, though the managers hardly mentioned benefits of proximity manufacturing under the environmental dimension and the product quality aspect of the business dimension, specialized suppliers and lower gas emissions are the most mentioned and the third most mentioned benefits, respectively.

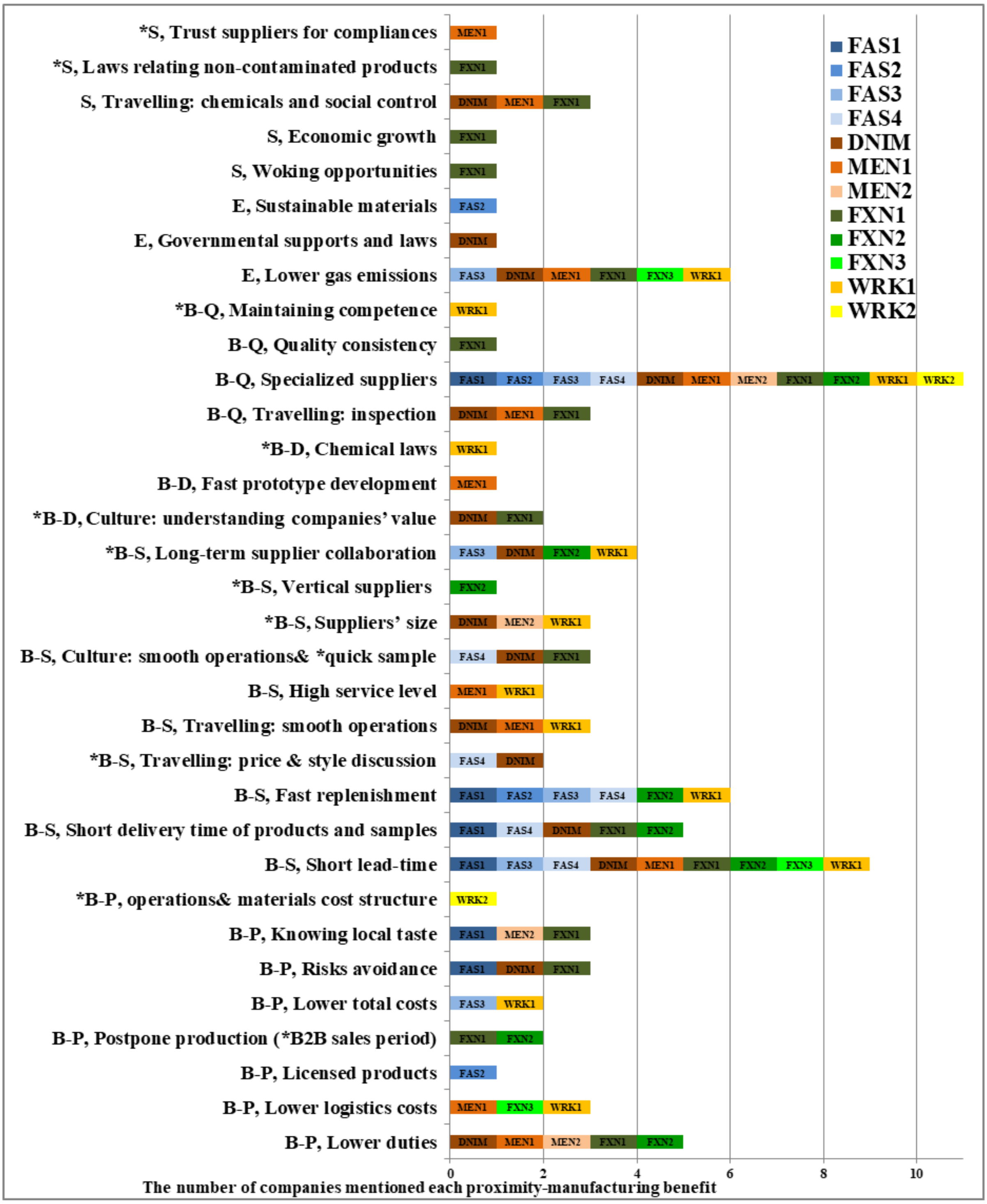

Figure 3.4 Benefits of proximity manufacturing mentioned by interviewees from twelve companies.

Remarks: * indicates new benefits from literature; B-P, B-S, B-D, and B-Q refer to profit, service and delivery, product/process development, and product quality under the business dimension; E and S are the environmental and social/socio-economic dimensions.

3.2.3 Distant Manufacturing Benefits

Benefits of distant manufacturing, which implies barriers to proximity manufacturing, are presented in Figure 3.5. Most mentioned benefits are under the business dimension involving profits and service and delivery aspects rather than product/process development and product quality. Relative low manufacturing cost at distant locations make managers decide to have distant manufacturing. Bangladesh is usually used for basic garment production because of very low labor cost while China whose labors are not cheap are used for sophisticated and fashion garment production.

According to Figure 3.5, the quality-related benefit (specialized and high-qualitied distant manufacturers) is the fifth most mentioned benefit of distant manufacturing. The other most mentioned benefits of distant manufacturing relate to manufacturing processes such as high European manufacturing costs, capacity problems from lacks of industry set-up and seamstresses in Europe, as well as existing good collaboration and relationship with local representative offices at distant manufacturing locations and distant manufacturers. Additionally, the FAS2 manager showed interesting distant-manufacturing benefits which are the incapability of Turkish proximity manufacturer for short sample development lead-time (10 weeks) and the competency of Bangladeshi vertical manufacturer for fast sample development (two weeks) and for in-house manufactured fabrics with stock. Therefore, the total lead-time from proximity manufacturing is indifferent from distant manufacturing. Anyway, FAS2 can still use the Turkey proximity manufacturer for fast replenishment after the sample has been developed with in-stock fabrics.

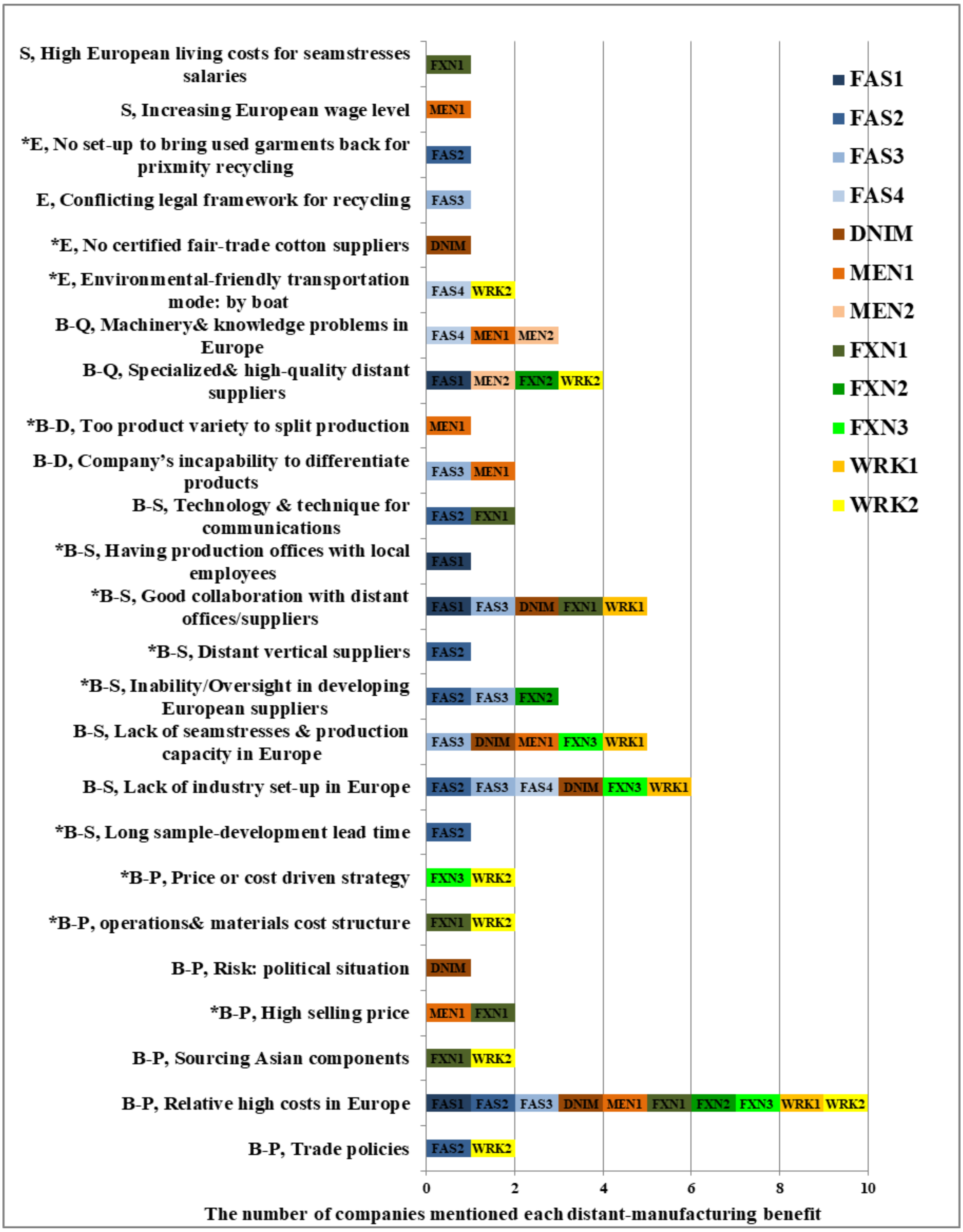

Figure 3.5 Benefits of distant manufacturing mentioned by interviewees from twelve companies.

Remarks: * indicates new benefits from literature; B-P, B-S, B-D, and B-Q is profit, service and delivery, product/process development, and product quality under the business dimension; E and S are the environmental and social/socio-economic dimensions.

From Figure 3.4 and Figure 3.5, there are common factors between proximity and distant manufacturing depending on which locations can offer better factor conditions. The common factors are good collaboration and relationship with existing manufacturers, the access to high-quality or vertical manufacturers, the proximity to specialized fabric suppliers, political risks, trade policies, and environmental legal framework especially for recycling.

3.2.4 Common and Contrast Benefits between Interviews and Literature

Results from the interviews show some similarities to the literature review in Chapter 2 for proximity benefits of textile and garment industries and Chapter 1.3.2 for general manufacturing location factors. The similarities are that most benefits of both proximity and distant manufacturing involve service and delivery as well as profit aspects of the business dimension. There is still the lacks of environmental and social/socio-economic related benefits. However, interviewing managers help reveal new benefits of proximity and distant manufacturing in addition to literature as marked with an asterisk (*) shown in Figure 3.4 and Figure 3.5. Furthermore, the interview results show the contrast between location and time context from the fact that Swedish manager interviews in 2017 showed their concerns on environmental and social aspects while American manager interviews in 1980s by Forney et al. (1990) showed their desires to relax social and environmental laws and restrictions.

Besides the easiness to travel to visit factors for environmental and social compliance control, the interview results demonstrate the responsibility to follow the REACH European chemical law to manufacture safe products for consumers as an benefit of proximity manufacturing in addition to literature. Ensuring environmental and social compliance at manufacturing locations enhances not only environmental and social sustainability by non-contaminated wastes and products but also business sustainability by avoiding reputational risks from malpractices (Srai & Ané, 2016). Moreover, the interview results also demonstrate government roles in sustaining the social dimension besides regulating the labor rights and minimum wages for workers as mentioned in literature. Therefore, government can set laws to prevent harmful chemical use in the manufacturing process in order to ensure the safety of workers, environment, and consumer. Additionally, the interview results present that the easiness to visit factories help reduce total lead-time because face-to-face discussion of garment style and price leads to quick finalization to start production faster.

On the other hand, some benefits of proximity manufacturing shown in literature were overlooked by the managers. None of managers talked about lowering gas emission by choosing factories using filtration technology or manufacturing locations using sustainable energy source which is a highly mentioned benefit of proximity manufacturing in European market studies relating to the environmental sustainability in the literature review in Chapter 2. Other unrealized benefits by managers, which were also barely mentioned in any literature, are emerging market and population density as well as gaining governmental supports on finance and delocalization, production technique, workers' training and education, and clusters and business collaboration. Therefore, managers may include the overlooked benefits of proximity manufacturing into their manufacturing strategies in the future to potentially enhance business and environmental sustainability.

Regarding benefits of distant manufacturing, the interview results reveal current benefits contrasting to literature implying the importance of time and industry/product type contexts. Complex products prefer proximity manufacturing due to specialization and technology (Bolisani & Scarso, 1996; Gray et al., 2017). However, the interviewed managers choose to manufacture high-fashion and complex garments with distant manufacturers because of their specialization and technology as well as, relative low costs for the number of operations minutes. However, the WRK2 manager mentioned that the product with expensive fabric and low operation minutes are suitable to manufacture in proximity locations to Europe. Therefore, the cost-structure of garments in terms of material and labor costs is an important factor of manufacturing location decisions besides the availability of skilled workers and supplier specialization mentioned in literature.

3.2.5 Relationships among Business Contexts, Benefits, and Manufacturing Location Decisions

Access to specialized fabric and garment suppliers in Europe is the main benefit of proximity manufacturing while relative high costs in Europe is the main benefit of distant manufacturing. All 11 companies, who have some proximity manufacturing, hire European suppliers to produce specialized products or materials in order to achieve high product quality despite their different organizational contexts such as product types, average selling price, and replenishment and stock policies. The reason could be that access to supplier knowledge is a driver of manufacturing location (Ellram et al., 2013) and that proximity to key suppliers and high quality suppliers are sustainability factors when choosing manufacturing location (Chen et al., 2014). Therefore, proximity manufacturing occurs when the access to specialized suppliers is a top criterion for choosing manufacturing locations and European suppliers are more competitive than distant suppliers in certain garment types required by the companies. On the other hand, the distant manufacturing occurs such as for FXN3 and WRK2 when a company is price-oriented. The FXN3's manager said, "it's a historical issue actually. Because we started the brand, in order to get into the market, we need to have price-driven, price-driven; and the only option it was at that time, at the end of 90s, was via, through China and Far East especially. "

Due to the short lead time from proximity manufacturing, the two companies (MEN1, WRK1) can maintain high service level to customers in terms of stock availability and provide customers value-added service such as special adjustment or add-ons for customers' special requests. Moreover, if an order is incorrect or defective, companies can substitute a new product to the old one quickly by using proximity manufacturing especially by a small production unit in Sweden for the main market in Nordics countries. Their strategies as a business context are similar in terms of guaranteeing business-to-business (B2B) clients to deliver orders immediately within a few days for high service level and offering value-added and after-sales services. Both of them can follow changing demand and have in-season replenishment quickly within one to two months by proximity manufacturing. On contrary, a distant-manufacturing oriented company (WRK2), who also focuses on offering high service level to B2B clients, has periodic replenishment every month for high-turnover garments rather than have in-season replenishment to follow current demand because the long production and delivery lead-time (8 months) from distant in-house manufacturing make WRK2 incapable to respond to changing demand as well as to offer value-added and after-sales services. It is noticeable that WRK1 does not have advanced fabric preparation before an order confirmation unlike MEN1 and WRK1. Therefore, advanced fabric preparation strategy may help companies capable of being responsive to demand especially for proximity manufacturing. Additionally, WRK2 chose to have in-house manufacturing of its workwear products in Asia due to its low-cost strategy for entering the market.

Managers from only five companies (FAS4, DNIM, MEN1, FXN1, and WRK1) see short travelling for style and price discussion, smooth operation assurance, and quality inspection as benefits of proximity manufacturing. The reason could be that the managers travel to visit factories by themselves rather than to rely on local representatives. Moreover, only FXN1 has no local representatives at distant manufacturing location and the other four of the five have more proximity manufacturing than distant manufacturing. The finding highlighted that having local representatives at manufacturing locations can be an benefit of distant manufacturing mentioned by the FAS1 manager.

In order to achieve fast prototype development, FXN1's strategy is using real garments as a ground for prototype development in order to increase garment suppliers' understanding to develop samples quickly and correctly. On the other hand, MEN1's strategy is using proximity manufacturing by having in-house prototype production at headquarters so that design team can check real looks to make adjustment quickly as well as feasibility of their designs for production running. Moreover, ability to know which product designs are feasible to production is considered as a competence of companies to create efficient production for high product quality. Therefore, WRK1 still has in-house manufacturing in proximity in order to maintain its competence.

Managers from five companies with high fabric control strategies (DNIM, MEN1, FXN1, FXN3, WRK1) focus on the proximity between fabric and garment manufacturing evidenced by the fact that they mentioned the benefits of fabric and garment manufacturing more than once (FAS4, and WRK2 mentioned only once). Moreover, their average retail price seems to be high (€51-€150 and more). Furthermore, almost all managers of the five companies, excepting FXN3, perceive short travelling as a proximity manufacturing benefit in order to visit suppliers for solving problems and operation control (DNIM, MEN1, WRK1), inspection and maintain quality (DNIM, MEN1, FXN1) and ensuring non-contaminated products (DNIM, FXN1). The high level of controlling fabrics and fabrics sources leads to smooth operation, high product quality and traceability in the supply chain. Additionally, all companies with majority of manufacturing in Europe (FAS4, DNIM, MEN1, and WRK1) have high fabric control strategies.

Three managers (FAS4, DNIM, FXN1) experience better collaboration with proximity manufacturers than distant manufacturers in terms of the way of thinking and doing business which enhance smooth operation, understanding companies' values, opened dialogue with each other, sample development processes and new product development. There are two possible reasons that help other six companies (FAS1, FAS2, FAS3, FXN2, WRK1, WRK2) who also work with both proximity and distant manufacturers to overcome some difficulties to cooperate with distant manufacturers. Firstly, the longer establishment and experience in the business (founded year) may help companies to choose suitable production location and suppliers matching to companies' values, to well cooperate with suppliers, and to have long-term suppliers. Second are having production/purchasing/buying offices, agents from big corporate group, or in-house factories in distant locations rather than hiring own agents.

There seems to be a relationship between the level of turnover and the concern on duty for saving costs. Companies (MEN2, FXN1) whose turnover is less than €15 million can avoid 10-12% of duty custom for made-in-Europe garments. Moreover, managers (DNIM, MEN1, FXN2) from medium-low turnover (€40-€80 million) are concerned about duty cost when importing from Europe to USA whereas the others whose turnover are more than €80 and €350 did not pay attention in saving costs from duty custom. In addition, the only company (WRK1), which focuses on the total-cost saving from proximity manufacturing such as lowering safety stock from short lead time leading to reducing warehouse cost and tied-up capita, has in-house manufacturing in proximity and the highest turnover which is about €400.

3.2.6 Conclusion and Implications

This chapter employs semi-structure interviews of managers from 12 Swedish clothing companies by using direct content analysis technique to extract information from interview transcripts and from company websites, online shops, financial reports, and sustainability reports as triangulated data and additional data. Within- and cross- case analysis are used to find factors and their relating business contexts of each company as well as the similarities and differences among the companies.

The interview results are concurrent to literature in terms of specialized supplier availability, short lead-time, and fast replenishment as proximity manufacturing benefits as well as of relative high European manufacturing costs, and the lack of industrial seamstresses and industrial set-up in Europe as distant manufacturing benefits. Moreover, discovered benefits of proximity manufacturing from the interview are garment cost structure between material and labor costs, short travelling for price and style discussion, and European chemical laws for social compliance, and product innovation. On the other hand, discovered benefits of distant manufacturing are company's inability to find European manufacturers, existing distant suppliers with good collaboration, local representatives at manufacturing locations, the lack of recycling infrastructure and laws, and manager concerns on high costs of living in Europe for seamstresses' salaries. Furthermore, common factors for manufacturing location decisions for both proximity and distant manufacturing include the proximity between fabric and garment manufacturers, good relationship and collaboration with existing manufacturers, the access to high-quality and vertical manufacturers, political risks, trade policies, and environmental laws and regulations.

3.2.6.1 Managerial Implications for Companies

Companies may consider proximity manufacturing as a sustainable practice in order to enhance sustainability and traceability of supply chains because proximity manufacturing helps not only the well-known short lead-time and fast response but also short travelling to visit factors for quality, as well as environmental and social compliance control. Moreover, in order to shorten total lead-time, it is necessary to choose manufacturers who get familiar with products and have abilities to develop samples fast. Visiting the manufactures in face-to-face helps shorten the total lead-time by quickly finalization of styles and prices to start production fast. Using real garments as a ground for prototype development and sending it to manufacturers can help the manufacturers to develop samples quickly and correctly leading to shortening sample development lead-time. Moreover, having small local in-house product units at headquarters and markets can help designers to develop prototypes quickly and feasible to production as well as companies to provide high service level to customers in terms of product customization and after-sale services. Lastly, fast replenishment can be achieved by having fabric preparation in advance or stock. Basic garments, and carry-over-style and never-out-of-stock garments help reduce risks from advanced fabric preparation by continuous demand and production as well as relative small number of items to be stocked.

3.2.6.2 Social Implications for Policy Makers

Policy makers potentially improve business, environmental, and social/socio-economic sustainability through supporting proximity manufacturing to their locations by creating favorable institutional infrastructure such as trade policies, efficient logistics, worker training, as well as chemical, environmental and social regulations. Moreover, as managers give high importance on the proximity between fabric and garment manufacturers, policy makers can support material suppliers to be competitive and vertical manufacturing in order to draw investment to their locations.

3.2.6.3 Research Limitations and Future Research Directions

Future research may further explored factors of proximity and distant manufacturing in other industries and market/headquarter countries and later compare with this study in order to see the possibility to generalize results. Furthermore, benefits of proximity and distant manufacturing from this chapter can be inputs to a model of manufacturing or supplier location decisions.

3.3 Study 3.1 The Twelve-Step Proposed Model for Designing Sustainable Multi-tier Supply Locations

The proposed model is shown in Figure 3.6 presenting not only activities in a product supply chain but also involving factors and summarized steps of the model. Figure 3.6 shows that all possible supply chain alternatives are uniquely generated by configuring all identified locations of multi-tier suppliers and warehouse(s). Different supply chain alternatives have different accumulated costs and CO2e due to locational-dependent factors from different locations of each tier supplier and different transportation routes. Suggested factors whose cost and CO2e should be considered for supply location decisions are shown in Figure 3.6. This proposed model allows users to calculate not only relative values but also absolute values of total cost and CO2e in a product supply chain according to their preferences and data availability. Calculating relative values by considering only differential cost and CO2e among different supply chain alternatives can help select relative better cost and CO2e supply chains from different alternatives.

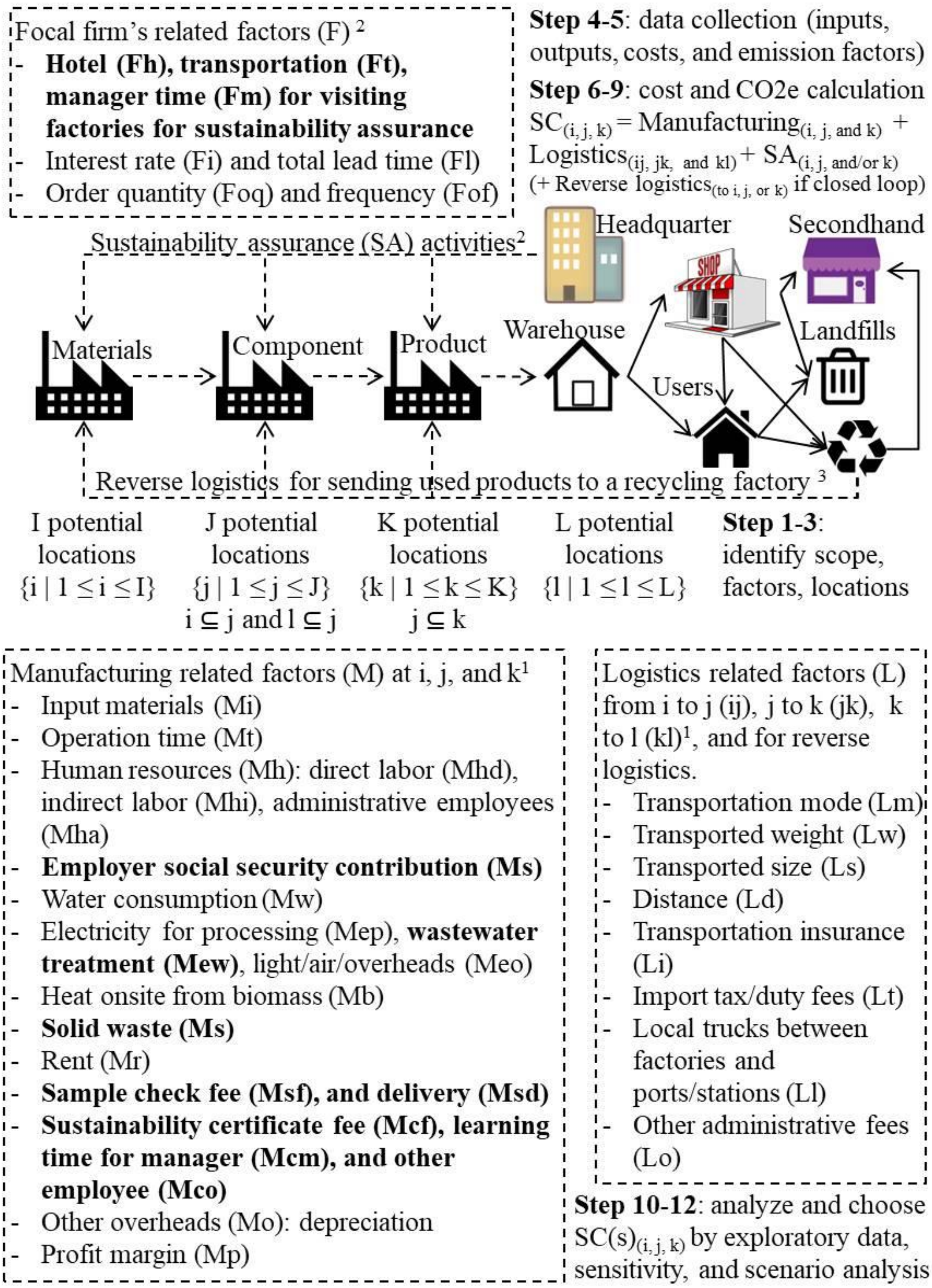

Figure 3.6 The twelve-step proposed model for sustainable multi-tier supply location decisions with cost and carbon dioxide equivalent (CO2e) criteria.

Remarks: Bold indicates unique factors from sustainability assurance activities performed by factories and focal firms that overlooked by traditional cost and/or CO2e computation; Dashed arrows show supply chain stages and activities whose cost and CO2e depends on locations; [1] for the landed computational scope; [2] added activities into 1 for the firm scope; and [3] added activities for the reverse-logistics scope.

If users want to calculate absolute values, they have to consider factors and activities aside from the dashed arrows in Figure 3.6 such as product design and development, distribution to shops, consumption, and sorting used products. These activities can be ignored for comparing different supply chain alternatives with differential values because these activities give equal values in every supply chain alternative for each market. Additionally, the proposed model including suggested factors in Figure 3.6 are derived from iterative processes during cost and CO2e calculation and analysis of the model application as well as feedbacks from other researchers what can be improved on.

This proposed model gives flexibility to users to choose a computational scope according to business contexts. For example, if a firm always send managers from its headquarter to check products and compliances at factories, the firm computational scope should be used to include the sustainability assurance activities performed by the firm into cost and CO2e calculation. Besides the bold factors indicated in Figure 3.6, the firm scope differentiates this model from other cost and environmental models for calculating cost and CO2e in forward supply chains. If a firm has a closed-loop supply chain for its products by sending used products back to materials, component, or product factories, the reverse logistics computational scope should be used to include the reverse logistics into the calculation for manufacturing location decisions.

According to Table 3.3 from Study 2, almost all of the studied companies have a part of product portfolio which are never-out-of-stock, carry over style to be produced in the following years, and reordered when there is high demand. The interviewees mentioned that these products are usually basic garments with repetitive productions that require only one time for factory visiting and sample development at the beginning. Therefore, their outsourcing setup costs can be allocated to units in several production batches. On the other hand, fashion and complex garments, which can be sold only one season due to out of trend in the following year or low sales, require factory visits/communication with factories and sample development for every production batch. Therefore, outsourcing setup costs can be allocated to only units in one production batch. It can be seen that different product types and control levels influence some activities in a product supply chain implying different costs and CO2e. Therefore, when using this proposed model, it is important to specify business contexts especially sustainability governance level and types of products. As the results, I proposed a scheme in Figure 3.7 in order to help users identify different business contexts, observed outcomes, and what are possibly included and analyzed in the proposed model.

The details for applying the twelve-step model are described as follow with a methodology framework of the twelve-step proposed model shown in Figure 3.8.

3.3.1 Step 1 Objective, Scope, and Activity Identification

The intended application, objective, computational scope, business context, and the other aspects mentioned in the model scheme in Figure 3.7 have to be identified in order to know activities and factors for cost and CO2e data collection and calculation. The analysis level and data type depend on intended model application and availability of data. Moreover, the objective has to include identified cost and CO2e preferences and constraints. The preferences and constraints have to align with the chosen computation scope and outputs whether they are absolute or relative values of the compared supply chain alternatives.

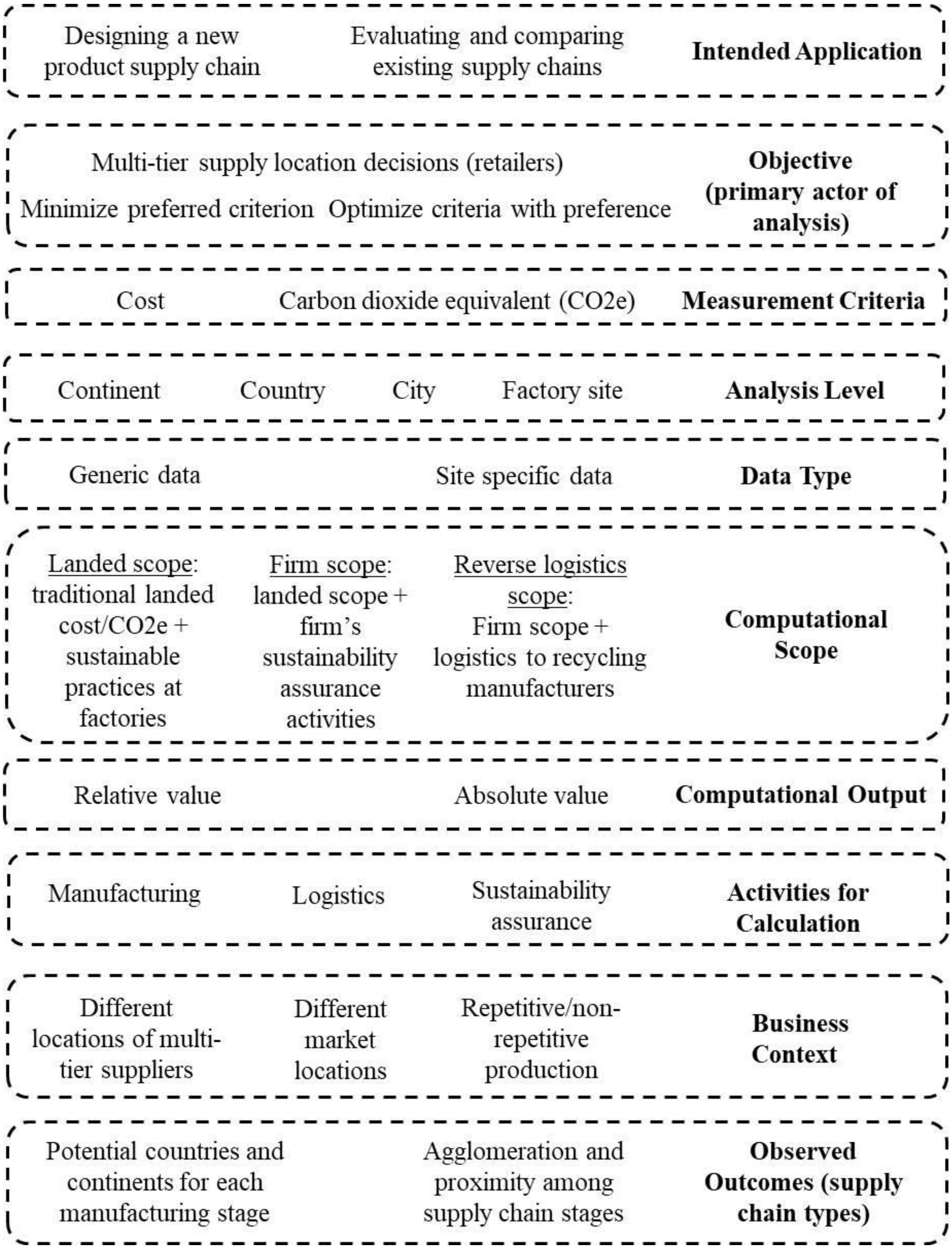

Figure 3.7 A scheme aiding the proposed model application for multi-tier supply location decisions.

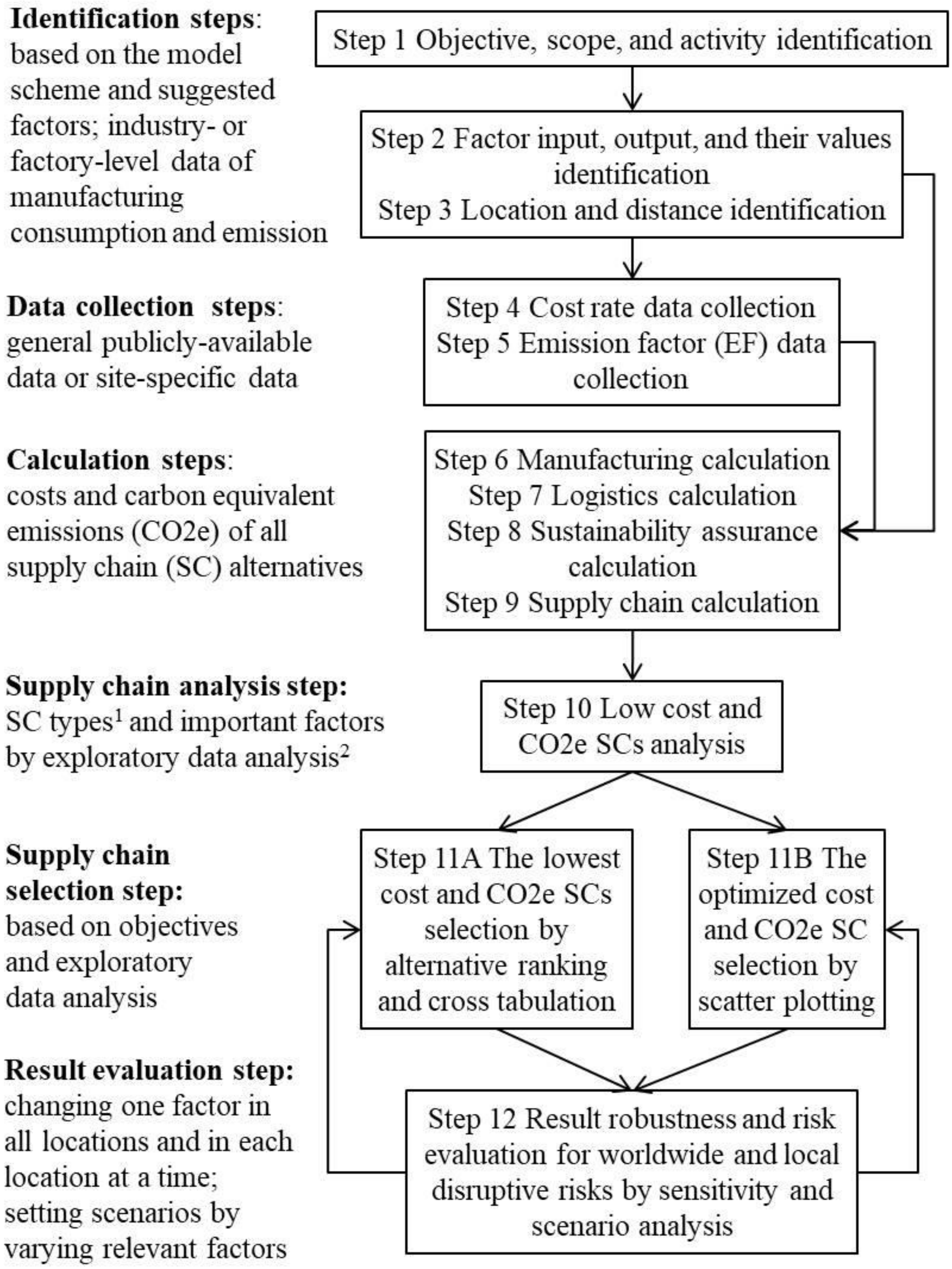

Figure 3.8 A methodology framework of the twelve-step proposed model (adapted from submitted paper).

Remarks: All data are stored in their own matrixes with the link to their coefficient matrixes which help varying manufacturing consumption and emission rates among different countries and conduct sensitivity and scenario analyses; [1]Supply chain types are varied by agglomeration and proximity among supply chain stages; [2]Exploratory data analysis include alternative ranking, cross tabulation, 2-D stack column graphs, and scatter plotting.

3.3.2 *Step 2 Factor Input, Output, and their Values Identification*

The logic models technique is used for identifying inputs and outputs of all manufacturing, logistics, and firm's sustainability assurance activities, which influence cost and CO2e (intermediate outcomes) and TBL sustainability (long-term outcomes), in every supply chain stage related to the scope identified in Step 1. The identified factors will help users know which cost and CO2e data to be collected and calculated in Step 4 to Step 9. The basic factors, which are applicable to most industries, are suggested in Figure 3.6. More factors can be added particular ones that are important to each industry. Values of the inputs and outputs (consumption and waste rates) depending on industries and factories are gathered in this step into manufacturing data matrixes. Every data matrix for this model is linked to its own coefficient matrix by multiply data with its coefficient value. The consumption and emission amounts of each factor can be found from data inventory of individual products for each industry or from factories if there are available data. Without factory-level data, users can use industry-level manufacturing data and set all coefficient values to 1. The coefficient values can later be varied in some supply chain alternatives whose locations have better or lower manufacturing productivity and technology. The coefficient matrixes are also useful for sensitivity and scenario analyses in Step 12.

The fact that the proposed model considers factors and calculation in many tiers with sustainability assurance activities is very useful because focal firms can estimate how much materials and product prices quoted by suppliers should be in order to ensure their abilities to meet product quality, environmental, and social requirements. According to the interviews with managers from Chapter 3, if a quoted price is much lower than the estimated one, it is skeptical how the supplier can bear the costs for manufacturing high product quality with good environmental and social practices.

3.3.3 Step 3 Location and Distance Identification

A few or many locations of each manufacturing stage and markets (including recycling locations if applicable) can be identified by supplier availability, reputation for producing certain materials and products, existing suppliers of firms, as well as the proximity to consecutive stages of its supply chain. As shown in Figure 3.6, the lists of component and final product manufacturing locations have to include locations of the farthest-tier suppliers (usually raw materials suppliers) and warehouses. After knowing the locations, all possible supply chain alternatives can be generated. For closed-loop supply chains, recycling locations depend on industries whether used products will be sent to final product, component, or raw materials manufacturers. Moreover, data on distance and time between each location are gathered in logistics data matrixes for later steps of logistics cost and CO2e calculation. Additionally, users can assign specific transportation mode or include all kinds of transportation modes for delivery goods between locations.

3.3.4 Step 4 Cost Rate Data Collection

Cost rates, prices, and fees of the identified factors from Step 2, which relate to manufacturing, logistics, and firm's sustainability assurance activities, are collected and stored in cost data matrixes. Their data depend on and vary according to locations and transportations. The data can be country/city-level data or site-specific data from factories (if available).

3.3.5 Step 5 Emission Factor Data Collection

EFs of CO2, CH4, and N2O, relating to the factors from Step 2 are collected and stored in CO2e data matrix. EFs can be found from research articles as well as online websites and platforms such as https://ghgprotocol.org/calculation-tools and www.ipccnggip.iges.or.jp/EFDB/main.php. Users have to use EFs from the same sources for factors which depend on locations such as electricity EFs. EFs of electricity consumed in each country are varied according to their energy source for electricity generation and loss in transmission. EFs for other energy consumption depending on energy sources can relate to either non-renewable energy use (NREU) and renewable energy use (REU) such as onsite heating from biomass and wood. Besides emissions from solid wastes on landfill, users may consider other relevant wastes to their industries. EFs of sample, product, and employee transportation depend on transportation modes.

In this step, users also choose values of Global Warming Potential (GWP) for converting CH4 and N2O into CO2 for CO2e calculation. GWP can be from the Intergovernmental Panel on Climate Change (IPCC) Report. According to the fifth assessment report of IPCC, GWP values for CH4 and N2O are 28 and 265, respectively.

3.3.6 Step 6 Manufacturing Calculation

The input and output values (consumption amount or emission amount) from Step 2 are multiplied with their own cost rates from Step 4 and EFs from Step 5 for cost and CO2e calculation, respectively. Different units have to be converted into the same units. Activity-based costing is used to allocate overheads, fixed, and indirect costs and CO2e into actual produced units which relate to the activities generated the costs and CO2e. For the costs related to time-based such as monthly or yearly fees, the costs are allocated into actual operating time of the factory to run the production batch by considering working-hour per day and working-day per month rather than 24 hours per day and 30 days per month. GWP values from Step 3 are used to convert the three gas emissions into CO2e by multiplying each GWP value to each gas emission value of the multiplication between EFs and the input/output values.

Manufacturing costs ($cost_M$) from the manufacturing related factors in Figure 3.6 are accumulated at each i, j, k manufacturing locations to be called as EXW price which is the price of materials or products available at the factory without logistics costs. The EXW price is calculated by the summation of the following formulas 1-14, the other overhead cost, and profit. Moreover, all consumption and output amount and time shown in the formulas are for producing the required order quantity per production batch. Unspecified acronyms refer to Figure 3.6.

$$\text{Material cost}_{Mi,\, i} = \text{amount}_{Mi} * \text{cost rate}_{Mi} \quad (1.1)$$

$$\text{Material cost}_{Mi,\, j/k} = \text{cost}_{M,\, i/j} + \text{cost}_{L,\, ij/jk} \quad (1.2)$$

If the cost $rate_{Mi}$ for inputs of the initial stage (i) is EXW price at the factory (i-1), logistics costs from i-1 to i location has to be included. Material $cost_{Mi}$ of subsequent stages (j and k) is calculated from the summation of manufacturing costs of the previous stage ($cost_{M,\, i/j}$) with logistics costs ($cost_{L,\, ij/jk}$).

$$\text{Direct labor cost}_{Mhd} = \text{machine/human time}_{Mt} * \text{number}_{Mhd} * \text{hourly wage}_{Mhd} \quad (2)$$

$$\text{Indirect labor cost}_{Mhi} = T_B * \text{number}_{Mhi} * \text{hourly wage}_{Mhi} \quad (3)$$

$$\text{Administrative employee cost}_{Mha} = T_B * \text{number}_{Mha} * \text{hourly wage}_{Mha} \quad (4)$$

T_B refers to total production time of each batch. Hourly wages refers to industrial wages or occupational wages for different skilled-workers and positions. The wages have to be equal or more than living wage of each location. If not, living wages should be used in order to ensure human right, social equality, and socio-economic sustainability.

$$\text{Water cost}_{Mw} = \text{amount}_{Mw} * \text{cost rate}_{Mw} \quad (5)$$

$$\text{Electricity cost} = \text{amount}_{(Mep+Mew+Meo)} * \text{electricity cost rate} \quad (6)$$

$$\text{Heat cost}_{Mb} = \text{amount}_{Mb} * \text{wood price} * \text{wood calorific values of fuel wood} \quad (7)$$

$$\text{Solid waste cost}_{Ms} = \text{amount}_{Ms} * \text{cost rate}_{Ms} \quad (8a)$$

$$\text{or} = T_B * \text{yearly fee}_{Ms} / T_F \quad (8b)$$

T_F refers to factory working hours per year. Solid wastes can be calculated based on amount or time depending on how factories pay fee to service providers. If the fee is a flat rate per year, formula 8b is used. For formula 8a, solid waste amount from processing can also from the difference between inputs and outputs.

$$\text{Rent}_{Mr} = T_B * \text{monthly fee}_{Mr} / T_F / 12 \quad (9)$$

$$\text{Sample check fee}_{Msf} = \text{lab test fee}_{Msf} / N_B \quad (10)$$

$$\text{Sample delivery cost}_{Msd} = \text{a package cost}_{Msd} * \text{the number of delivery}_{Msd} / N_B \quad (11)$$

N_B is the number of production batch. It is used for allocating sample check costs into the number of batches produced with the tested materials or components and the checked product sample. Sustainability assurance costs are allocated into the number of production batches before the next visit of an employee from headquarter for new styles and products as well as for solving problems.

$$\text{Sustainability certificate fee}_{Mcf} = (\text{certificate fee}_{sMcf} + \text{auditing fee}_{Mcf}) * T_B / (\text{the number of certified year} * T_F) \quad (12)$$

$$\text{Sustainability certificate employee costs} = \text{learning time}_{Mcm,Mco} * \text{hourly wage} * T_B / (\text{the number of certified year} * T_F) \quad (13)$$

$$\text{Employer social security contribution cost}_{Ms} = \text{rate}_{Ms}*(\text{cost}_{Mhd} + \text{cost}_{Mhi} + \text{cost}_{Mha} + \text{sustainability certificate employee costs}) \quad (14)$$

For the other overheads cost, users may use actual costs from factories or estimate it by multiplying a percentage with the summation of formulas 1-14. After that, profit margin for i, j, k manufacturers can be estimated by multiplying a percentage with the summation of formulas 1-14 and the other overheads cost. The percentages for the other overheads and profit margin depend on industries. Finally, the summation of formulas 1-14, the other overheads cost, and the profit margin is EXW price of materials, components, or products to the next supply chain tier/stage. The summation of EXW price and logistics costs to the location of the next stage is landed cost of materials, components, or products.

Manufacturing CO2e is derived from the summation of CO2e from activities relating to factors shown in Figure 3.6 at each i, j, k manufacturing locations. Each activity CO2e is calculated by the following formula.

$$CO2e_M = ((EF_{CO2}*GWP_{CO2}) + (EF_{CH4}*GWP_{CH4}) + (EF_{N2O}*GWP_{N2O}))* \text{Manufacturing activity rate} \quad (15)$$

Manufacturing activity rates defined in Step 2 are amounts of consumed electricity for processing (Mep), wastewater treatment (Mew), and light/air/overheads (Meo), of heat onsite generated by biomass (Mb), of solid wastes to landfill (Ms), and of delivered samples (Msd) and distance from factories to the headquarter and laboratory for quality and chemicals checking. Each EF collected in Step 5 is aligned to each factor of manufacturing activity rates.

3.3.7 Step 7 Logistics Calculation

Logistics cost calculation include international transportation, freight insurance, domestic transportation to/from ports in case of ship, import duties, and port fees. The transportation and insurance costs can be obtained from logistics providers or from the multiplication among size and/or weight of transported goods from Step 2, distance data from Step 3, and transportation cost rate from Step 4. The import duties can be calculated by multiplying import duty rates from Step 4 with the summation of domestic and international transportation costs, insurance cost, and EXW price from the previous stage. Logistic CO2e can be calculated by multiplying distance data from Step 3 with EFs of transportation mode from Step 5 and use GWP values from Step 3 for CO2e conversion. The calculation of logistic costs and CO2e for each transportation route from i to j (ij), j to k (jk), and k to l (kl) locations are summarized in the following formulas. Acronyms refer to Figure 3.6.

$$Cost_L = cost(_{Lm,\ Lw\ or\ Ls,\ Ld})+cost_{Li}+cost_{Lt}+cost_{Lo}(+cost_{Ll}) \quad (16)$$

$$CO2e_L = ((EF_{CO2}*GWP_{CO2})+(EF_{CH4}*GWP_{CH4})+(EF_{N2O}*GWP_{N2O}))* \\ weight*distance \quad (17)$$

$CO2e_L$ includes both domestic and international transportations and their EFs depend on transportation mode. Cost and CO2e from reverse logistics back to any suppliers (i, j, and/or k) are also calculated according to the formulas 16 and 17.

3.3.8 Step 8 Firm Sustainability Assurance Calculation

Sustainability assurance cost calculation for firms to visit multi-tier supplier factories relates to transportation costs of employees to travel, hotel costs, and employee costs in terms of travel time for work. Sustainability assurance CO2e relates only the employee transportation. Their calculations are similar to the other activities by multiplying input and output values from Step 2 with their own cost rates from Step 4 and EFs from Step 5. Interest rate is also included in the calculation relating to firm cash flow for ensuring business sustainability. GWP values from Step 5 are used for obtaining CO2e values from GHG emissions.

Sustainability assurance costs incurred at the focal firm are calculated as follows. Acronyms refer to Figure 3.6.

$$Cost_F = cost_{Fh}+cost_{Ft}+cost_{Fm}+cost_{Fi} \quad (18)$$

$$Cost_{Fh} = \text{hotel night rate*the number of travelling nights for a factory visit} \quad (19)$$

$$Cost_{Ft} = \text{domestic transportation costs + international transportation cost} \quad (20)$$

$$Cost_{Fm} = \text{hourly wage*the number of travelling hours} \quad (21)$$

$$Cost_{Fi} = \text{yearly rate}_{Fi}/365*(\text{total cost}_M+\text{total cost}_L+ cost_{Fh}+cost_{Ft}+cost_{Fm})* \text{total lead-time from manufacturing, logistics, and firm activities} \quad (22)$$

Sustainability assurance CO2e includes both domestic and international transportations of passengers and their EFs depend on transportation mode. Passenger transportation CO2e is calculated according to the following formula.

$$CO2e_F = ((EF_{CO2}*GWP_{CO2})+(EF_{CH4}*GWP_{CH4})+(EF_{N2O}*GWP_{N2O}))*\text{distance} \quad (23)$$

3.3.9 Step 9 Supply Chain Calculation

Depending on the computational scope (Figure 3.7), supply chain cost and CO2e calculation are from combining the manufacturing, logistics, and sustainability assurance costs and CO2e from Step 6-8 at each i, j, and k manufacturing location shown in Figure 3.6. The formula for calculating supply chain cost and CO2e is shown below.

Supply chain cost = manufacturing cost(i, j, and k)+logistics cost(ij, jk, and kl)+

firm cost(i, j, and/or k) (+reverse logistics(to i, j, or k) if closed loop (24)

Supply chain CO2e = manufacturing CO2e(i, j, and k)+logistics CO2e(ij, jk, and kl)+

firm CO2e (i, j, and/or k) (+reverse logistics(to i, j, or k) if closed loop (25)

3.3.10 Step 10 Low Cost and CO2e Supply Chain Analysis

This step helps reveal supply chain types potentially generating low cost and CO2e as well as important cost and CO2e factors of the product supply chain. The low cost/CO2e alternatives and their values for each warehouse/market are revealed by the alternative ranking of all alternatives from low to high cost and CO2e. The low cost/CO2e alternatives can be defined by users' constrains or preferences on cost and CO2e value. If there is no constrain and preference, users may choose to analyze alternatives in the 90th, 95th, or 99th percentile ranking (the 10%, 5%, and 1% lowest cost/CO2e alternatives).

After knowing the low cost/CO2e alternatives, cross tabulation between countries/continents of each manufacturing stage and agglomeration between consecutive supply chain stages are used to reveal potential countries and continents for each manufacturing stage and agglomeration/proximity between supply chain stages in order to potentially achieve low cost/CO2e supply chains. The results show potential low cost/CO2e supply chain types for the product for all markets. All markets can simultaneously be compared by the cross tabulation. The analysis of agglomeration and proximity can be locations between raw material and intermediate/component manufacturing, intermediate/component and final product manufacturing, final product manufacturing and markets, markets and recycling manufacturing, intermediate/component manufacturing and headquarter of firms, and final product manufacturing and headquarter of firms. The results can lead users to consider outsourced materials or products from vertical suppliers.

After that, 2-D stack column graphs plotting are used to reveal important factors of not only low cost/CO2e alternatives but also all alternatives for each market. Knowing important factors help users realize what could be risk factors to impact the product supply chains. The impact level of the important risk factors will be shown in Step 12 by sensitivity and scenario analyses.

3.3.11 Step 11 Supply Chain Selection

This step has two options depending on users' objectives on either the lowest cost and CO2e supply chains or the optimized cost and CO2e supply chains for each market and all markets. For the lowest cost/CO2e supply chain, users know it since the previous step by the alternative ranking technique. Users can further use cross tabulation for comparing results of all markets in order to see common low cost and CO2e alternatives. Moreover, users possibly analyze either one computational scope defined in Step 1 or more than one computational scopes for long-term planning of production and business strategies on product types, supply chain and sustainability governance, and forwarded- or closed-loop product supply chains.

For deriving an optimized cost and CO2e supply chain, scatter plotting is used to reveal optimal low cost-CO2e alternatives on its Pareto frontier to be called as Pareto frontier alternatives which are multi-criteria solutions for conflicting objectives (Lotov, 2004) such as economic and environmental aspects. If users have specific cost and CO2e constraints or goals, they can easily exclude and include certain alternatives by drawing a line from x-axis and y-axis of the scatter plot. Users can also find common Pareto frontier alternatives among different markets by cross tabulation. The results of this step usually show a set of optimized cost and CO2e supply chain alternatives; therefore, users can choose one from the common alternatives according to users' preferences and constraints on cost, CO2e, and other qualitative factors such as cultural and linguistic preference, political situation in the country, superior skills of certain suppliers, governmental support, and trust in suppliers. Some supply chain alternatives with high risks can be eliminated after sensitivity and scenario analyses in Step 12. This step will be repeatedly performed together with Step 12 as shown in Figure 3.8.

Users can further conduct scatter plotting between cost and CO2e *with categorical colors* in order to visualize different supply chain types according to the categorical colors assigned by users. It is an iterative process to find a categorical criterion which reveals certain patterns aiding users to design their supply chains. Possible categorical criteria adapted from location and agglomeration literature (McCann & Shefer, 2004; Weber, 1929) are distance to market, agglomeration between supply chain stages, and low/high cost locations. From the iterative simulations of the model application in the following section, I categorize alternatives according to their component and final product manufacturing locations in terms of continents to order to see different groups with different proximity to markets and agglomeration between component and final product manufacturing locations. Scatter plotting with categorical colors by component and final product manufacturing locations helps reveal which locations for each stage have high potentials to create low cost and CO2e supply chains or to meet users' constraints and goals.

3.3.12 Step 12 Result Robustness and Risk Evaluation

This step adopts sensitivity and scenario analysis for evaluating robustness of the model results and risks. Changing values of input factors imitate different what-if situations which help users foresee their impact on competitiveness and attractiveness of locations (Tate et al., 2014). For sensitivity analysis, cost and CO2e factors relating to consumption rates, cost rates, and EFs are varied in order to see how results are sensitive to input factors if there are disruption or changed environments. Users can perceive important factors, which change the lowest cost/CO2e supply chain (Step 10) or the optimized cost and CO2e supply chains (Step 11) of the base-case scenario by decreasing and increasing factor values or by setting target results to investigate ranges of factor values. There are two kinds of factor value changing. First is to vary each factor value of all locations at the same time in order to observe impacts from worldwide disruptive events (macro level). Second is to vary each factor value of each location individually at a time in order to observe impacts from possible local disruptive events (micro level). The factors that change the base-case results are considered as important factors and possible risks to affect the designed supply chains in the future.

Besides investigating different situations and environments from factor sensitivity analysis, scenario analysis by setting different situations can be used to observe target results and ensure the design supply networks are robust. Different scenarios can come from potential problems such as trade war for duty fees among countries and the important factors from Step 10 or the sensitivity analysis. After changing different factor values and scenarios, common alternatives to different scenarios should be chosen because they are resistant to different situations and environments implying a robust supply network for ensuring smooth operations and avoiding switching costs (Ferdows, 1997).

3.3.13 Conclusion and Implications

The proposed model shows the potentials to reveal the lowest cost and carbon dioxide equivalent (CO2e) supply chain alternatives with different computational scopes and markets as well as important factors and future risks. The model also shows the flexibility to generate different scenarios and manage disruptive events as well as the potential to quantify gaps (cost and CO2e differences) among different scenarios aiding short and long-term decision making. Users can set their own cost and CO2e preferences and constraints in order to choose one of the very low cost and CO2e supply chains resulted from the model. The results from comparing different computational scopes demonstrate that reverse logistics cost and CO2e are more than firm cost and CO2e and the traditional landed cost and CO2e calculation results in the lowest values. Therefore, users with cost and CO2e constraints have to be careful when using the landed computational scope and I suggest using firm or reverse logistics computational scopes for designing supply locations of forward- and closed-loop supply chains, respectively.

3.4 Study 3.2 The Model Application in Viscose T-shirt Supply Chains

This model application involves finding multi-tier supply locations for manufacturing 1,800 viscose t-shirts for each batch. In this section, some results will show names of supply chain alternatives with combinations of country acronyms referring to locations of fiber, fabric, and garment manufacturing, respectively, with/without warehouse locations. For example, AT-AT-AT-DE refers to fiber, fabric, and garment manufacturing in Austria (AT) for the warehouse in Germany (DE). Country acronyms are AT (Austria), CN(NJ) (China (Nanjing)), ID (Indonesia), GB (Great Britain), US (the United States), TH (Thailand), DE (Germany), IT (Italy), PL (Poland), LT (Lithuania), TN (Tunisia), EG (Egypt), TR (Turkey), CN/CN(SH) (China (Shanghai)), and BD (Bangladesh).

3.4.1 Step 1 to Step 3: Identification

According to the model scheme in Figure 3.7, the intended application is to design a new product supply chain which has an optimized cost and CO2e supply chain by using generic data at city/country and industry level because it is assumed to be a new product line without existing suppliers who can provide specific data from their factories. The computational scope is the firm scope because there will be a business trip to visit new fabric and garment suppliers for sustainability assurance. However, for demonstrating the model application and potentials, I will show results of all three computational scopes as well as how to select the lowest cost and CO2e supply chains for each of and all three markets. In this model application, the reverse-logistic scope will be called as “the worn scope” for representing sending worn garments back to recycling factories. Regarding business contexts, the control level starts from a fiber supplier. The order of 1,800 t-shirts can possibly be either one time or repeated depending on sales. Therefore, one of scenario analysis is to analyze supply chain cost and CO2e for different number of manufacturing batches. Due to limited data, I compare supply chain alternatives with relative values of total costs and CO2e.

The Step 1 to Step 9 are shown in Figure 3.9. Figure 3.9 shows all three computational scopes whose results will be shown in the next step to demonstrate and compare different computational scopes to readers and users. However, the main computational scope of this model application is the firm cost and CO2e computational scope.

In Figure 3.9, the identified factors in Step 2 are based on Figure 3.6. The factors are from the logic models technique which helps identify inputs and outputs of activities for manufacturing viscose t-shirts from fiber to final garment stages. Figure 3.9 shows three tiers of suppliers: fiber, fabric, and garment manufacturers. Thread spinning, knitting and dyeing processes as well as cutting and sewing processes are included manufacturing activities. The calculation of cost and CO2e in supply chains includes identified factors in Step 2 as shown in Figure 3.9 and the input consumption rates and output waste rates of the identified factors are collected from secondary data sources such as academic studies and industrial practices.

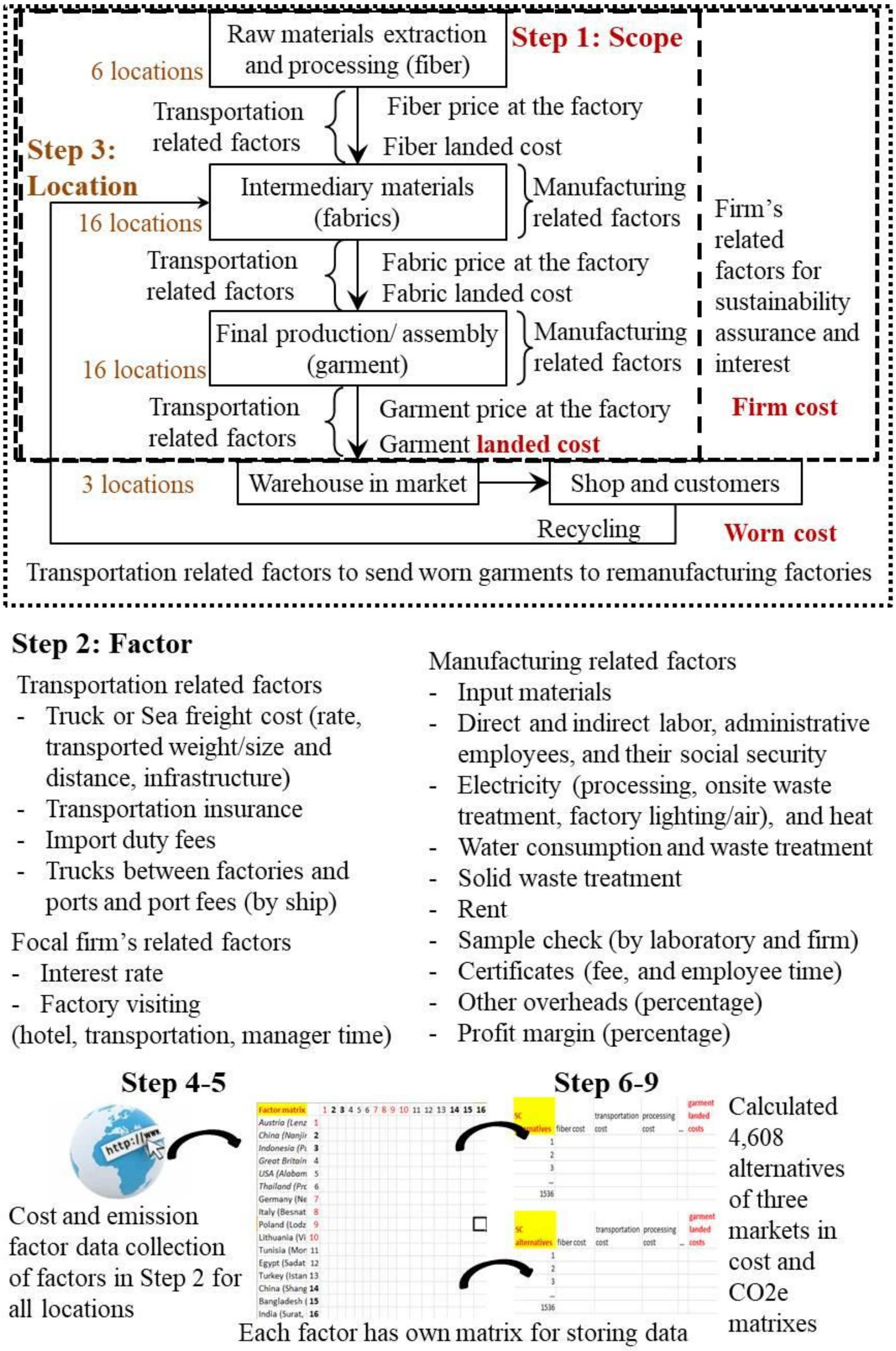

Figure 3.9. Step 1 to Step 9 of the twelve-step model application in the textile and clothing supply chain (adapted from the submitted paper).

Inventory data for producing a viscose t-shirt starting from fiber consumption process are from Angelstam, Artman, Hanström, Rodríguez, and Uskali (2016). Fiber production data are from L. Shen and Patel (2010). Manufacturing data are in Table B.1 to Table B.8 in Appendix B.

For Step 3, the location identification starts from fiber locations which are based on Lenzing viscose company whose website shows information of fiber manufacturing locations and emissions in many continents. I assume that all six fiber manufacturing locations shown in Figure 3.10 can produce viscose fiber though only some locations are producing viscose fiber at the moment. Based on current fiber-manufacturing technology of Lenzing, only manufacturing in Austria has environmentally-friendly technology. After that the six fiber locations and the location of the main warehouse and headquarter in Germany are assumed to produce fabrics and garments. This allows us to see the influence of both agglomeration among supply chain stages, as well as distance between firm and factories, on cost and CO2e. The fabric and garment location identifications are also based on common manufacturing practices from the interviewed companies in Chapter 3 together with the availability of suppliers from online market search. Fabric and garment manufacturing locations are shown in Figure 3.10. They are located in Western European countries as local manufacturing, in Eastern European and African countries as nearshoring manufacturing, and in South and East Asian countries and The United States (US) as offshoring manufacturing to the home market in Europe. Moreover, I added Shanghai as another manufacturing location besides Nanjing where fiber is produced in order to see the influence of inland logistics to cost and CO2e.

When simulating four-tier supply chains by sending finished products to individual warehouses in each of the three markets, the warehouse locations are from the identified garment manufacturing locations as shown in Figure 3.10. This helps reveal the influence of distance between market and garment manufacturing location. Additionally, the data of distance among the locations are based on a logistic provider website according to transportation mode of each transportation route (www.searates.com).

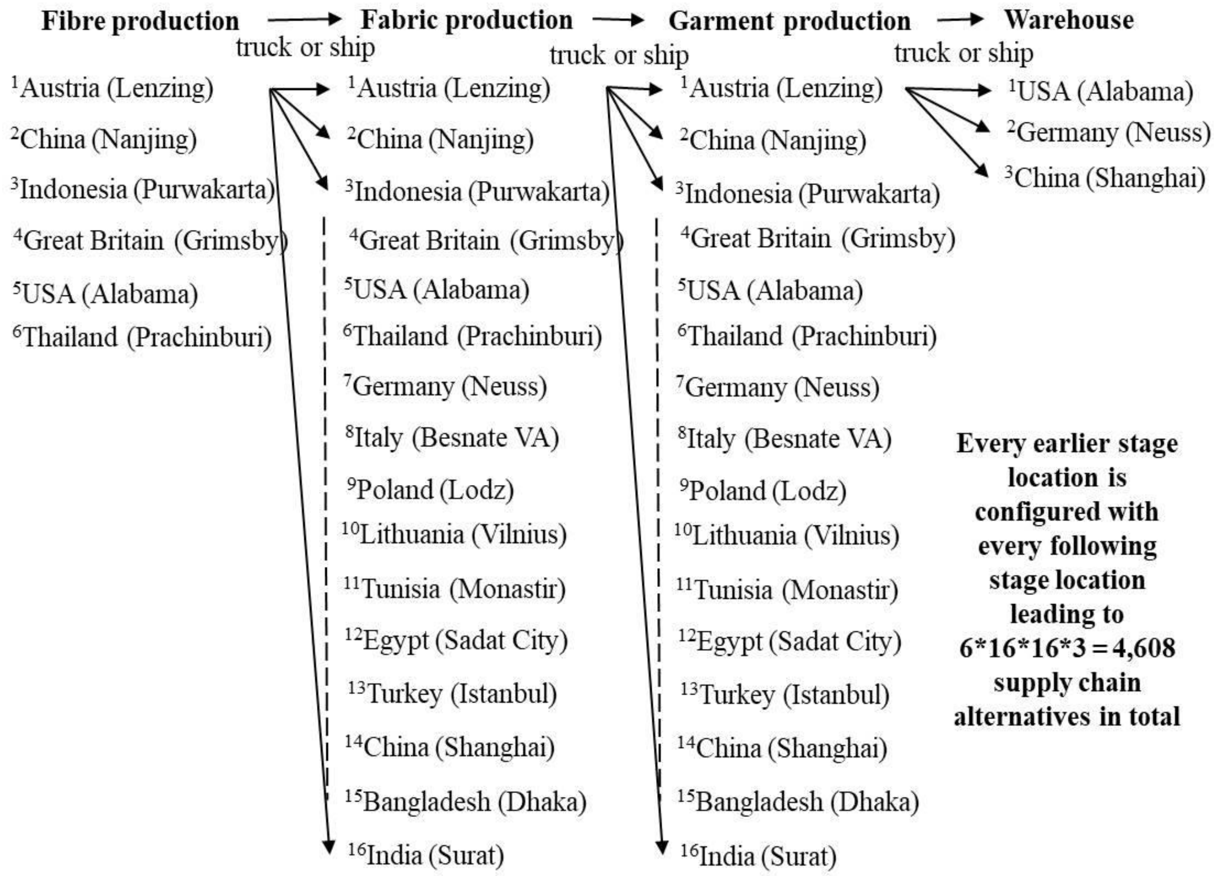

Figure 3.10. Location identification with transportation modes in the model application.

Remark: The major transportation mode is ship excepting domestic transportation to/from ports and between two cities in China as well as transportation among Germany, Italy, Poland, and Lithuania; and the numbers are used for indexing factor values of each location.

3.4.2 Step 4 to Step 5: Data collection

For Step 4 and Step 5, all cost/fee and EFs/CO2e rates of the identified factors in Step 2 are from secondary data sources such as published articles, governmental and professional reports and databases, as well as logistics, hotel, flight, and rental space service providers' websites. Cost data for manufacturing and sustainability assurance activities are in Table C.1 to Table C.8 in Appendix C. Logistic costs are searched during March - April 2019 from www.searates.com and www.worldfreightrates.com/freight. Freight insurance rates are from a service provider website (www.freightinsurancecenter.com/freightinsuranceonlinerates.htm). Transportation cost rates are shown in Table C.9 while import duty fees of fibers, fabrics, t-shirts, and used garments are shown in Table C.10 to Table C.13 in Appendix C. The insurance rates for domestic transportation by truck and for international by ship are 0.55 and 0.87 euro per 100 euros of insured FOB value. There is a minimum charge at 45 euros. Import duties are searched during 17th-25th December 2019 from www.simplyduty.com/import-calculator/. For EFs, consumption electricity EFs are searched on 29th April 2019 from https://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf, 2011 and the other EFs are from https://ghgprotocol.org/calculation-tools, Excel Sheet emission factor tool, March 2017 (latest access on 2019/12/25).

3.4.3 Step 6 to Step 9: Cost and CO2e calculation

For Step 6 to Step 8, the cost and CO2e calculation of manufacturing, logistics, and firm's sustainability assurance activities are calculated by multiplying the input consumption rates and output waste rates from Step 2 and transportation distance from Step 3 with their cost and CO2e rates from Step 4 and Step 5. After that cost and CO2e of each supply chain alternative (Step 9) are calculated by combing the results from Step 6, Step 7, and Step 8. The example of supply chain cost and CO2e are shown in Figure D.1 and Figure D.2 in Appendix D.

3.4.4 Step 10 Low cost and CO2e supply chain analysis

Alternative ranking and cross tabulation help users realize where to source fiber (raw materials) and manufacture fabric and garment (components and final products) for each market or all markets. The percentage of lowest cost/CO2e alternatives to be analyzed depends on users' constraints or goals. I use the 1% lowest cost/CO2e alternatives according to the previous-mentioned objective to show this model application. The 1% lowest cost alternatives and their values of producing 1,800 t-shirts to each of the three warehouses for each computational scope ("landed cost", "firm cost", and "worn cost") are shown in Table 3.5, Table 3.6, and Table 3.7. The tables demonstrate that different computational scopes show different accumulated costs and lowest alternatives of each market.

Table 3.5 The 1% lowest landed cost alternatives and their values for 1,800 t-shirts for each market warehouse.

Rank	US landed cost	€	DE landed cost	€	CN landed cost	€
1	ID-ID-ID-US	5,078	ID-ID-ID-DE	4,025	ID-ID-ID-CN(S)	3,668
2	CN(N)-BD-BD-US	5,410	CN(N)-BD-BD-DE	4,031	CN(N)-ID-ID-CN(S)	4,341
3	ID-BD-BD-US	5,432	ID-BD-BD-DE	4,048	ID-ID-CN(N)-CN(S)	4,586
4	US-TN-TN-US	5,520	ID-ID-BD-DE	4,190	ID-ID-TH-CN(S)	4,606
5	ID-ID-BD-US	5,614	US-TN-TN-DE	4,198	CN(N)-BD-BD-CN(S)	4,628
6	CN(N)-TN-TN-US	5,715	US-EG-EG-DE	4,200	ID-BD-BD-CN(S)	4,648
7	US-EG-EG-US	5,718	ID-EG-EG-DE	4,208	TH-ID-ID-CN(S)	4,673
8	ID-EG-EG-US	5,729	TH-BD-BD-DE	4,320	TH-TH-TH-CN(S)	4,677
9	TH-BD-BD-US	5,780	CN(N)-TN-TN-DE	4,350	CN(N)-BD-ID-CN(S)	4,730
10	ID-TN-TN-US	5,791	CN(N)-EG-EG-DE	4,403	ID-BD-ID-CN(S)	4,746
11	CN(N)-ID-ID-US	5,941	ID-TN-TN-DE	4,410	US-ID-ID-CN(S)	4,783
12	CN(N)-EG-EG-US	5,980	TH-EG-EG-DE	4,481	CN(N)-CN(N)-CN(N)-CN(S)	4,804
13	AT-BD-BD-US	5,990	AT-BD-BD-DE	4,484	ID-ID-BD-CN(S)	4,815
14	TH-EG-EG-US	6,078	ID-ID-EG-DE	4,503	ID-ID-CN(S)-CN(S)	4,888
15	ID-ID-EG-US	6,107	AT-EG-EG-DE	4,644	US-TN-TN-CN(S)	4,926
16	TH-TN-TN-US	6,140	TH-TN-TN-DE	4,682	US-EG-EG-CN(S)	4,928

Remarks: Alternative names refer to locations of fiber, fabric, and garment manufacturing, and warehouse; AT= Austria, CN(NJ)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, TH= Thailand, DE= Germany, TN= Tunisia, EG= Egypt, CN/CN(SH)= China (Shanghai), BD= Bangladesh.

Table 3.6 The 1% lowest firm cost alternatives and their values for 1,800 t-shirts for each market warehouse.

Rank	US firm cost	€	DE firm cost	€	CN firm cost	€
1	US-TN-TN-US	9,253	US-EG-EG-DE	7,768	US-EG-EG-CN(S)	8,505
2	US-EG-EG-US	9,299	ID-EG-EG-DE	7,777	ID-EG-EG-CN(S)	8,515
3	ID-EG-EG-US	9,310	US-TN-TN-DE	7,921	ID-ID-ID-CN(S)	8,631
4	CN(N)-TN-TN-US	9,449	CN(N)-EG-EG-DE	7,973	US-TN-TN-CN(S)	8,660
5	ID-TN-TN-US	9,526	TH-EG-EG-DE	8,051	CN(N)-EG-EG-CN(S)	8,746
6	CN(N)-EG-EG-US	9,561	CN(N)-TN-TN-DE	8,074	TH-TH-TH-CN(S)	8,836
7	TH-EG-EG-US	9,661	ID-TN-TN-DE	8,134	TH-EG-EG-CN(S)	8,837
8	AT-EG-EG-US	9,871	AT-EG-EG-DE	8,215	CN(N)-TN-TN-CN(S)	8,840
9	TH-TN-TN-US	9,877	GB-EG-EG-DE	8,301	ID-TN-TN-CN(S)	8,910
10	GB-EG-EG-US	9,982	TH-TN-TN-DE	8,408	AT-EG-EG-CN(S)	9,030
11	ID-ID-ID-US	10,059	ID-TR-TR-DE	8,520	GB-EG-EG-CN(S)	9,131
12	AT-TN-TN-US	10,088	US-TR-TR-DE	8,521	TH-TN-TN-CN(S)	9,232
13	GB-TN-TN-US	10,198	AT-TN-TN-DE	8,572	CN(N)-TH-TH-CN(S)	9,245
14	CN(N)-BD-BD-US	10,320	US-PL-PL-DE	8,634	ID-TH-TH-CN(S)	9,305
15	ID-BD-BD-US	10,341	GB-TN-TN-DE	8,658	CN(N)-ID-ID-CN(S)	9,308
16	ID-TR-TR-US	10,424	AT-PL-PL-DE	8,685	AT-TN-TN-CN(S)	9,425

Remarks: Alternative names refer to locations of fiber, fabric, and garment manufacturing, and warehouse; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, TH= Thailand, DE= Germany, PL= Poland, TN= Tunisia, EG= Egypt, TR= Turkey, CN/CN(S)= China (Shanghai), BD= Bangladesh.

Table 3.7 The 1% lowest worn cost alternatives and their values for 1,800 t-shirts for each market warehouse.

Rank	US worn cost	€	DE worn cost	€	CN worn cost	€
1	US-TN-TN-US	11,180	US-EG-EG-DE	9,229	ID-ID-ID-CN(S)	10,080
2	CN(N)-TN-TN-US	11,376	ID-EG-EG-DE	9,237	US-TN-TN-CN(S)	10,406
3	ID-TN-TN-US	11,453	CN(N)-EG-EG-DE	9,434	CN(N)-TN-TN-CN(S)	10,586
4	US-EG-EG-US	11,651	TH-EG-EG-DE	9,511	ID-TN-TN-CN(S)	10,656
5	ID-EG-EG-US	11,662	US-TN-TN-DE	9,673	US-EG-EG-CN(S)	10,701
6	TH-TN-TN-US	11,804	AT-EG-EG-DE	9,675	ID-EG-EG-CN(S)	10,711
7	CN(N)-EG-EG-US	11,914	US-PL-PL-DE	9,709	TH-TH-TH-CN(S)	10,719
8	TH-EG-EG-US	12,013	AT-PL-PL-DE	9,760	CN(N)-ID-ID-CN(S)	10,757
9	AT-TN-TN-US	12,014	GB-EG-EG-DE	9,761	CN(N)-EG-EG-CN(S)	10,942
10	GB-TN-TN-US	12,125	CN(N)-TN-TN-DE	9,826	TH-TN-TN-CN(S)	10,978
11	ID-TR-TR-US	12,200	ID-TN-TN-DE	9,886	CN(N)-BD-BD-CN(S)	11,006
12	US-TR-TR-US	12,202	ID-TR-TR-DE	9,972	ID-BD-BD-CN(S)	11,026
13	AT-EG-EG-US	12,224	US-TR-TR-DE	9,973	TH-EG-EG-CN(S)	11,033
14	GB-EG-EG-US	12,334	ID-PL-PL-DE	9,983	TH-ID-ID-CN(S)	11,091
15	CN(N)-TR-TR-US	12,491	CN(N)-PL-PL-DE	10,006	ID-TR-TR-CN(S)	11,108
16	CN(N)-BD-BD-US	12,575	TH-TN-TN-DE	10,160	US-TR-TR-CN(S)	11,110

Remarks: Alternative names refer to locations of fiber, fabric, and garment manufacturing, and warehouse; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, TH= Thailand, DE= Germany, PL= Poland, TN= Tunisia, EG= Egypt, TR= Turkey, CN/CN(S)= China (Shanghai), BD= Bangladesh.

Comparison of Table 3.5, Table 3.6, and Table 3.7 show that the worn cost and firm cost computations not only significantly increase landed costs but also change the 1% lowest alternatives (16 alternatives). Therefore, it is necessary to include costs from sustainability assurance activities by focal firms for forward supply chains and reverse logistics for closed loop supply chains. The comparison surprisingly shows that Bangladesh, which is a well-known manufacturing location for basic garments, is only competitive under the traditional landed cost computational scope and not competitive under the firm and worn computational scopes. Table 3.5, Table 3.6, and Table 3.7 also show that costs for warehouses in the United States and China are higher than costs for the warehouse in Germany. Therefore, users and future researchers may add more locations in and nearby the United States and China in order to see whether new supply chains with the added locations can generate much lower costs than the existing supply chains. This will benefit feasibility analysis whether to have split production among different markets. Additionally, the column of CN landed cost in Table 3.5 reveals that the landed cost gets more influenced by low manufacturing costs than by low logistics costs especially when comparing the alternatives with garment manufacturing in Nanjing to Shanghai where the warehouse is located in.

Descriptive cost data for all three markets and three computational scopes are shown in Table E.1 in Appendix E. Among three computational scopes, the gaps of cost and its percentage between the lowest cost alternative and the highest cost alternative or the 16th lowest cost alternative are decreasing from landed cost, firm cost, and worn cost scopes, respectively.

For CO2e, the 1% lowest CO2e alternatives and their values of three markets are different from the low-cost alternatives as shown in Table 3.8, Table 3.9, and Table 3.10 for each computational scope. The results obviously present that Austrian fiber gives low CO2e alternatives for every computational scope and market due to the fiber-manufacturing technology. Germany and nearby countries become more competitive for fabric and garment manufacturing after including sustainability assurance activities because of short distance to headquarter. Descriptive CO2e data of the markets and computational scope are shown in Table E.2 in Appendix E.

Table 3.8 The 1% lowest landed carbon dioxide equivalent (CO2e) alternatives and their values for 1,800 t-shirts for each market warehouse.

Rank	US landed CO2e	kgCO2e	DE landed CO2e	kgCO2e	CN landed CO2e	kgCO2e
1	AT-AT-AT-US	5,543	AT-AT-AT-DE	5,408	AT-AT-AT-CN(S)	5,574
2	AT-AT-LT-US	5,596	AT-AT-LT-DE	5,547	AT-AT-LT-CN(S)	5,705
3	AT-LT-LT-US	5,597	AT-LT-LT-DE	5,548	AT-LT-LT-CN(S)	5,706
4	AT-LT-AT-US	5,755	AT-LT-AT-DE	5,620	AT-LT-AT-CN(S)	5,786
5	AT-AT-IT-US	5,782	AT-IT-AT-DE	5,675	AT-AT-IT-CN(S)	5,835
6	AT-IT-AT-US	5,810	AT-AT-IT-DE	5,689	AT-IT-AT-CN(S)	5,841
7	AT-IT-LT-US	5,847	AT-IT-LT-DE	5,798	AT-AT-EG-CN(S)	5,951
8	AT-GB-LT-US	5,866	AT-EG-AT-DE	5,804	AT-IT-LT-CN(S)	5,956
9	AT-TN-LT-US	5,920	AT-AT-GB-DE	5,814	AT-EG-AT-CN(S)	5,971
10	AT-IT-IT-US	5,921	AT-TN-AT-DE	5,815	AT-IT-IT-CN(S)	5,974
11	AT-AT-GB-US	5,921	AT-GB-LT-DE	5,816	AT-GB-LT-CN(S)	5,975
12	AT-EG-LT-US	5,926	AT-DE-AT-DE	5,826	AT-TN-AT-CN(S)	5,982
13	AT-EG-AT-US	5,939	AT-IT-IT-DE	5,828	AT-DE-AT-CN(S)	5,992
14	AT-TN-AT-US	5,950	AT-LT-GB-DE	5,869	AT-AT-TN-CN(S)	6,017
15	AT-AT-EG-US	5,943	AT-TN-LT-DE	5,871	AT-TN-LT-CN(S)	6,029
16	AT-AT-US-US	5,943	AT-GB-AT-DE	5,874	AT-AT-GB-CN(S)	6,029

Remarks: Alternative names refer to locations of fiber, fabric, and garment manufacturing, and market; AT= Austria, GB= Great Britain, US= the United States, DE= Germany, IT= Italy, LT= Lithuania, TN= Tunisia, EG= Egypt, TR= Turkey, CN/CN(S)= China (Shanghai).

Table 3.9 The 1% lowest firm carbon dioxide equivalent (CO2e) alternatives and their values for 1,800 t-shirts for each market warehouse.

Rank	US firm CO2e	kgCO2e	DE firm CO2e	kgCO2e	CN firm CO2e	kgCO2e
1	AT-AT-AT-US	6,256	AT-AT-AT-DE	6,122	AT-AT-AT-CN(S)	6,288
2	AT-DE-DE-US	6,330	AT-DE-DE-DE	6,190	AT-DE-AT-CN(S)	6,364
3	AT-DE-AT-US	6,333	AT-DE-AT-DE	6,198	AT-DE-DE-CN(S)	6,437
4	AT-AT-DE-US	6,389	AT-AT-DE-DE	6,248	AT-AT-DE-CN(S)	6,496
5	AT-AT-LT-US	6,487	AT-DE-GB-DE	6,393	AT-AT-IT-CN(S)	6,552
6	AT-DE-GB-US	6,500	AT-IT-AT-DE	6,392	AT-IT-AT-CN(S)	6,558
7	AT-AT-IT-US	6,499	AT-AT-IT-DE	6,406	AT-DE-IT-CN(S)	6,576
8	AT-DE-LT-US	6,511	AT-DE-IT-DE	6,431	AT-AT-LT-CN(S)	6,596
9	AT-DE-IT-US	6,523	AT-AT-LT-DE	6,438	AT-DE-GB-CN(S)	6,608
10	AT-IT-AT-US	6,526	AT-IT-DE-DE	6,460	AT-DE-LT-CN(S)	6,620
11	AT-AT-GB-US	6,590	AT-DE-LT-DE	6,462	AT-LT-AT-CN(S)	6,677
12	AT-IT-DE-US	6,601	AT-AT-GB-DE	6,483	AT-IT-IT-CN(S)	6,694
13	AT-GB-DE-US	6,644	AT-GB-DE-DE	6,503	AT-AT-GB-CN(S)	6,698
14	AT-IT-IT-US	6,641	AT-LT-AT-DE	6,511	AT-IT-DE-CN(S)	6,707
15	AT-LT-AT-US	6,645	AT-GB-AT-DE	6,543	AT-GB-AT-CN(S)	6,709
16	AT-LT-LT-US	6,665	AT-IT-IT-DE	6,548	AT-GB-DE-CN(S)	6,751

Remarks: Alternative names refer to locations of fiber, fabric, and garment manufacturing, and market; AT= Austria, GB= Great Britain, US= the United States, DE= Germany, IT= Italy, LT= Lithuania, CN/CN(S)= China (Shanghai).

Table 3.10 The 1% lowest worn carbon dioxide equivalent (CO2e) alternatives and their values for 1,800 t-shirts for each market warehouse.

Rank	US worn CO2e	kgCO2e	DE worn CO2e	kgCO2e	CN worn CO2e	kgCO2e
1	AT-DE-DE-US	6,721	AT-DE-DE-DE	6,190	AT-AT-AT-CN(S)	6,902
2	AT-DE-AT-US	6,723	AT-DE-AT-DE	6,198	AT-DE-AT-CN(S)	7,051
3	AT-AT-AT-US	6,783	AT-AT-AT-DE	6,274	AT-AT-DE-CN(S)	7,110
4	AT-DE-GB-US	6,891	AT-DE-GB-DE	6,393	AT-DE-DE-CN(S)	7,124
5	AT-DE-LT-US	6,902	AT-AT-DE-DE	6,401	AT-IT-AT-CN(S)	7,130
6	AT-DE-IT-US	6,914	AT-DE-IT-DE	6,431	AT-AT-IT-CN(S)	7,166
7	AT-AT-DE-US	6,916	AT-DE-LT-DE	6,462	AT-AT-LT-CN(S)	7,210
8	AT-IT-AT-US	6,951	AT-GB-DE-DE	6,565	AT-DE-IT-CN(S)	7,263
9	AT-GB-DE-US	7,002	AT-AT-IT-DE	6,558	AT-IT-IT-CN(S)	7,266
10	AT-AT-LT-US	7,014	AT-IT-AT-DE	6,564	AT-IT-DE-CN(S)	7,279
11	AT-IT-DE-US	7,026	AT-AT-LT-DE	6,590	AT-DE-GB-CN(S)	7,295
12	AT-AT-IT-US	7,026	AT-GB-AT-DE	6,604	AT-DE-LT-CN(S)	7,307
13	AT-GB-AT-US	7,036	AT-IT-DE-DE	6,632	AT-AT-GB-CN(S)	7,312
14	AT-IT-IT-US	7,066	AT-AT-GB-DE	6,635	AT-GB-AT-CN(S)	7,367
15	AT-GB-LT-US	7,070	AT-GB-GB-DE	6,714	AT-GB-DE-CN(S)	7,409
16	AT-LT-AT-US	7,101	AT-IT-IT-DE	6,721	AT-IT-LT-CN(S)	7,422

Remarks: Alternative names refer to locations of fiber, fabric, and garment manufacturing, and market; AT= Austria, GB= Great Britain, US= the United States, DE= Germany, IT= Italy, LT= Lithuania, CN/CN(S)= China (Shanghai).

3.4.4.1 Agglomeration and proximity among supply chain stages

In order to analyze whether agglomeration among locations of supply chain manufacturers, warehouse, and firm influence the low cost/CO2e alternatives, I investigate different types of agglomeration between two locations: fiber and fabric factories, fabric and garment factories, garment factories and warehouse, warehouse and recycling factory, fabric factory and firm, as well as garment factory and firm. I counted the number of supply chain alternatives, which have aforementioned agglomeration, from the 1% lowest cost/CO2e alternative for each country and each continent shown in Table 3.11, Table 3.12, Table 3.13, and Table 3.14, respectively.

Table 3.11 Countries and the number of supply chain alternatives (in parenthesis) with location agglomeration from the 1% lowest-cost alternatives for three computational scopes and three warehouses.

Types of location agglomeration	US landed cost	DE landed cost	CN landed cost	US firm cost	DE firm cost	CN firm cost	US worn cost	DE worn cost	CN worn cost
Fiber and fabric	ID(3)	ID(3)	CN(N)(1), ID(5), TH(1)	ID(1)		ID(1), TH(1)			ID(1), TH(1)
Fabric and garment	ID(2), TN(4), EG(4), BD(4)	ID(1), TN(4), EG(5), BD(4)	CN(N)(1), ID(4), TH(1), TN(1), EG(1), BD(2)	ID(1), TN(6), EG(6), TR(1), BD(2)	PL(2), TN(6), EG(6), TR(2)	ID(2), TH(3), TN(5), EG(6)	TN(6), EG(6), TR(3), BD(1)	PL(4), TN(4), EG(6), TR(2)	ID(3), TH(1), TN(4), EG(4), TR(2), BD(2)
Garment and market			CN(S)(1)						

Remarks: CN(N)= China (Nanjing), ID= Indonesia, US= the United States, TH= Thailand, DE= Germany, PL= Poland, TN= Tunisia, EG= Egypt, TR= Turkey, CN/CN(S)= China (Shanghai), BD= Bangladesh; No agglomeration between warehouse and recycling locations, fabric manufacturing and firm, and garment manufacturing and firm.

Table 3.12 Continents and the number of supply chain alternatives (in parenthesis) with location agglomeration from the 1% lowest-cost alternatives for three computational scopes and three warehouses.

Types of location agglomeration	US landed cost	DE landed cost	CN landed cost	US firm cost	DE firm cost	CN firm cost	US worn cost	DE worn cost	CN worn cost
Fiber and fabric	AS(7)	AS(6)	AS(13)	AS(3)	EU(1)	AS(5)	AS(1)	EU(1)	AS(6)
Fabric and garment	AF(8), AS(7)	AF(9), AS(6)	AF(2), AS(14)	EU(1), AF(12), AS(3)	EU(4), AF(12)	AF(11), AS(5)	EU(3), AF(12), AS(1)	EU(6), AF(10),	EU(2), AF(8), AS(6)
Garment and warehouse			AS(14)		EU(4)	AS(5)		EU(6)	AS(6)
Warehouse and recycling			AS(14)		EU(4)	AS(5)		EU(6)	AS(6)
Fabric and firm				EU(1)	EU(4)		EU(3)	EU(6)	EU(2)
Garment and firm				EU(1)	EU(4)		EU(3)	EU(6)	EU(2)

Remarks: US= the United States, DE= Germany, CN= China (Shanghai), AS= Asia, AF= African, EU= Europe.

Table 3.13 Countries and the number of supply chain alternatives (in parenthesis) with location agglomeration from the 1% lowest-carbon dioxide equivalent (CO2e) alternatives for three computational scopes and three warehouses.

Types of location agglomeration	US landed CO2e	DE landed CO2e	CN landed CO2e	US firm CO2e	DE firm CO2e	CN firm CO2e	US worn CO2e	DE worn CO2e	CN worn CO2e
Fiber and fabric	AT(6)	AT(4)	AT(6)	AT(5)	AT(5)	AT(5)	AT(5)	AT(5)	AT(5)
Fabric and garment	AT(1), IT(1), LT(1)	AT(1), IT(1), LT(1)	AT(1), IT(1), LT(1)	AT(1), DE(1), IT(1), LT(1)	AT(1), DE(1), IT(1)	AT(1), DE(1), IT(1)	AT(1), DE(1), IT(1)	AT(1), GB(1), DE(1), IT(1)	AT(1), DE(1), IT(1)
Garment and warehouse	US(1)				DE(4)			DE(4)	
Warehouse and recycling		DE(1)			DE(5)			DE(5)	
Fabric and firm		DE(1)	DE(1)	DE(5)	DE(5)	DE(5)	DE(5)	DE(5)	DE(5)
Garment and firm				DE(4)	DE(4)	DE(4)	DE(4)	DE(4)	DE(4)

Remarks: AT= Austria, GB= Great Britain, US= the United States, DE= Germany, IT= Italy, LT= Lithuania, CN= China (Shanghai).

Table 3.14 Continents and the number of supply chain alternatives (in parenthesis) with location agglomeration from the 1% lowest-carbon dioxide equivalent (CO2e) alternatives for three computational scopes and three warehouses.

Types of location agglomeration	US landed CO2e	DE landed CO2e	CN landed CO2e	US firm CO2e	DE firm CO2e	CN firm l CO2e	US worn CO2e	DE worn CO2e	CN worn CO2e
Fiber and fabric	EU(12)	EU(13)	EU(13)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)
Fabric and garment	EU(10)	EU(13)	EU(11)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)
Garment and warehouse	US(1)	EU(16)			EU(16)			EU(16)	
Warehouse and recycling		EU(13)			EU(16)			EU(16)	
Fabric and firm	EU(12)	EU(13)	EU(13)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)
Garment and firm	EU(14)	EU(16)	EU(14)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)	EU(16)

Remarks: US= the United States, DE= Germany, CN= China (Shanghai), AS= Asia, AF= African, EU= Europe.

The results of agglomeration and proximity analysis show users that which countries and continents are suitable for which supply chain stage agglomeration for different markets and computational scopes in order to make low cost and CO2e supply chains. Surprisingly, at the country level analysis, the location agglomeration between warehouse and worn-garment recycling, fabric manufacturing and firm's headquarter, and garment manufacturing and firm's headquarter do not generate any 1% lowest-cost ranking as shown in Table 3.11. When considering more low-cost alternatives from the 10% lowest-cost ranking, the results are similar to the 1% ranking consideration that the agglomeration between fabric and garment manufacturing followed by between fiber and fabric manufacturing have potentials to delivery low-cost supply chains. However, the 10% ranking consideration additionally shows that agglomeration between garment manufacturing and warehouses in China (Shanghai) as well as between warehouse and worn-garment recycling in China (Shanghai) possible generate low-cost supply chains. Moreover, Table 3.11 and Table 3.12 show that all of the 1% low cost alternatives (16 alternatives) with firm and worn cost computational scopes for all three warehouses have the agglomeration between fabric and garment manufacturing. Table 3.14 highlighted the importance of proximity among locations of different supply chain stages including firm location, especially in Europe, on the 1% lowest CO2e alternatives.

3.4.4.2 Important cost and CO2e factors

2-D stack column graphs help reveal important factors to calculated costs and CO2e. Firstly, all alternatives for all three markets are plotted to compare three markets as well as low and high cost/CO2e alternatives as shown in Figure 3.11. As I focus on analyzing the firm scope in this model application, the alternatives are ranked by the firm costs/CO2e.

Figure 3.11 illustrates similar results of cost factors among the three markets. The difference is that garment duty has more influential to US market alternatives than German and Chinese market alternatives. Moreover, costs to firm to visit factories to assure sustainability are important factors especially employee and transportation costs. The reason is that the total costs of visiting factories are assigned to only one-batch of 1,800 garment manufacturing. This point leads to different scenario analysis of the important factors in the later step by varying the number of manufacturing batches for the one-time visiting factory costs in order to see how the factors influence low cost alternatives. After that only the 1% lowest cost/CO2e alternatives are plotted by the factor stack column graphs. An example of cost factor breakdown among the 1% lowest cost alternatives of the EU market is shown in Figure 3.12. The 1% lowest cost breakdown plots of the other markets of are shown in Figure E.1 and Figure E.2 in Appendix E. All three market plots of cost factor breakdown demonstrate that logistics for sending worn garments back to recycling factories change the cost competitiveness of the 1% lowest firm cost alternatives.

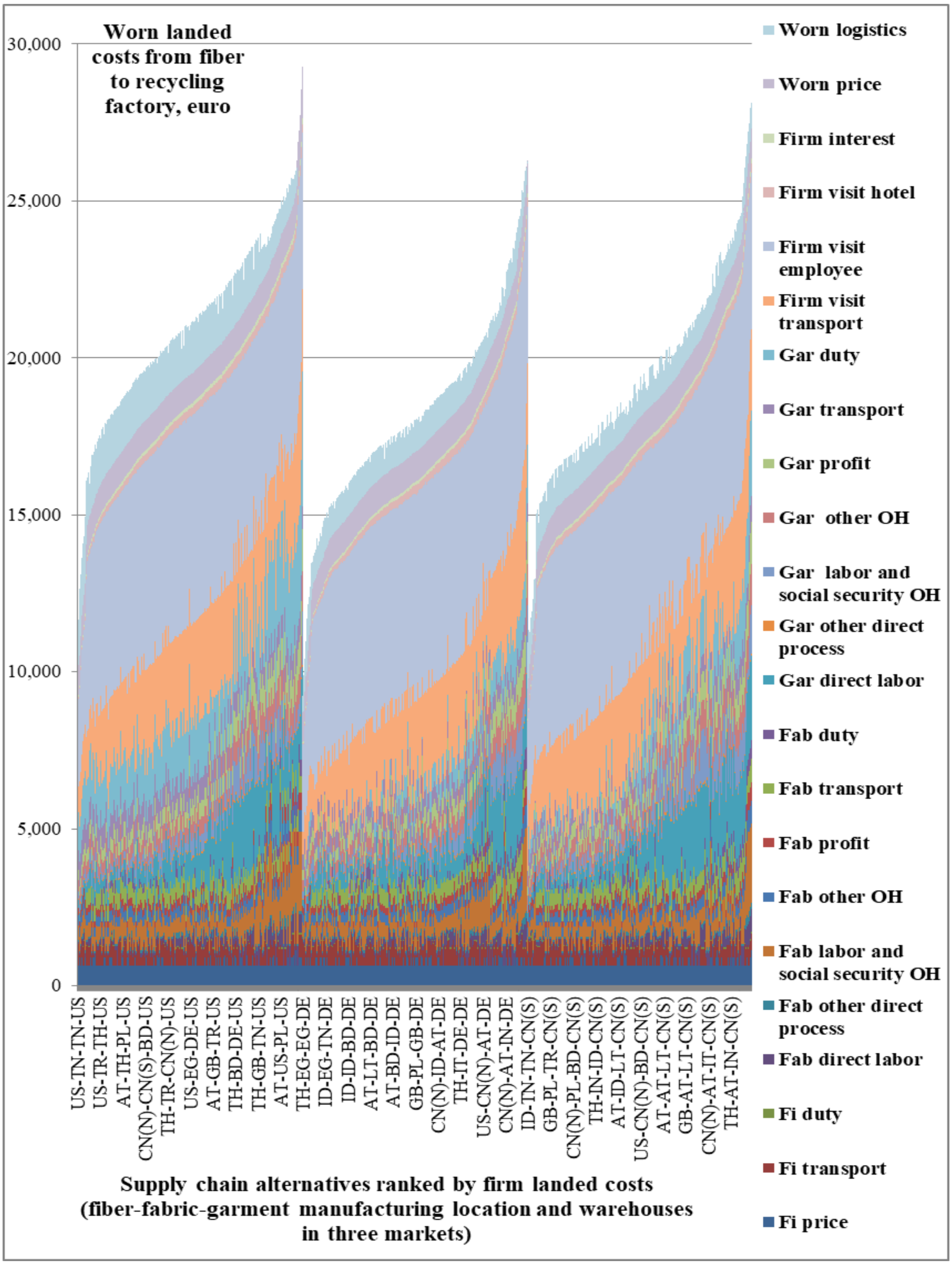

Figure 3.11 Cost-factor graph plotting of all 4,608 alternatives with three markets showing 1,800 t-shirt worn costs of all alternatives ranked by firm costs.

Remarks: Only some alternative names are shown; Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, OH= overheads; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, TH= Thailand, DE= Germany, IT= Italy, PL= Poland, LT= Lithuania, TN= Tunisia, EG= Egypt, TR= Turkey, CN/CN(S)= China (Shanghai), BD= Bangladesh, IN= India.

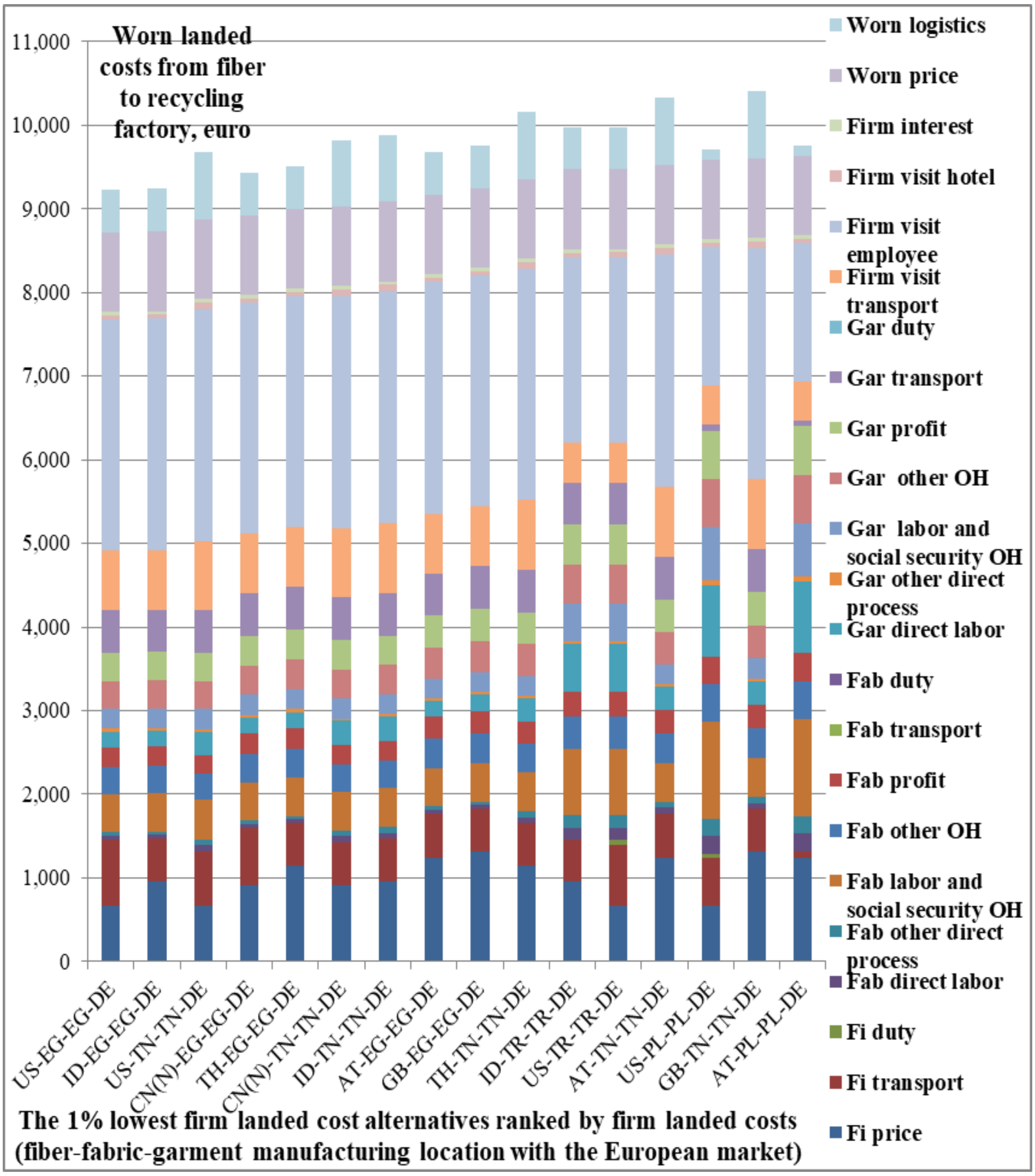

Figure 3.12 Cost-factor graph plotting of 1,800 t-shirt worn costs ranked by the 1% lowest firm cost alternatives with the warehouse in Germany

Remarks: Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, OH= overheads; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, TH= Thailand, DE= Germany, PL= Poland, TN= Tunisia, EG= Egypt, TR= Turkey.

Figure 3.12 shows that all 1% lowest firm cost alternatives of all three markets do not have fiber duty, fabric transportation, and fabric duty excepting two European-market alternatives which have fiber duty. Furthermore, the European-market low cost alternatives do not have garment duty.

For CO2e analysis, Figure 3.13 illustrates worn CO2e of all alternatives from the three markets. It can be seen that fiber manufacturing CO2e from NREU and REU as well as factory visit CO2e are important factors. Similar to factory visit cost, factory visit CO2e will be further investigated by different scenarios. Furthermore, Figure 3.13 shows different computational scopes change CO2e competitiveness of alternatives. When considering until garment transport CO2e, some medium worn and firm CO2e alternatives are low landed CO2e alternatives.

With the focus on the 1% lowest firm CO2e of each market, an example of CO2e factor breakdown among the 1% lowest CO2e alternatives of the EU market is shown in Figure 3.14. The 1% lowest CO2e breakdown plots of the other markets of are shown in Figure E.3 and Figure E.4 in Appendix E. All three-market CO2e breakdown reveal that the factory visit CO2e are not important factors for the low CO2e alternatives and the fiber NREU and REU CO2e are crucial factors contributing to worn CO2e more than 50 percent. The results of CO2e factor breakdown show that CO2e from energy use in the fiber manufacturing stage are the main part of all CO2e for all US, German, and Chinese markets. This is concurrent to Egilmez, Kucukvar, and Tatari (2013) that energy use is the most influential to eco-efficiency of US manufacturing sectors. However, the findings contrast to European data (https://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-by-sector-in/download.table) showing that the recent year GHG emissions from transportation is more than from manufacturing. The reasons of the differences could be the fact that most manufacturing sectors are located outside EU. Therefore, there is the need to calculate emissions from the entire product supply chain in order to avoid consumption countries transferring and hiding emissions to manufacturing countries.

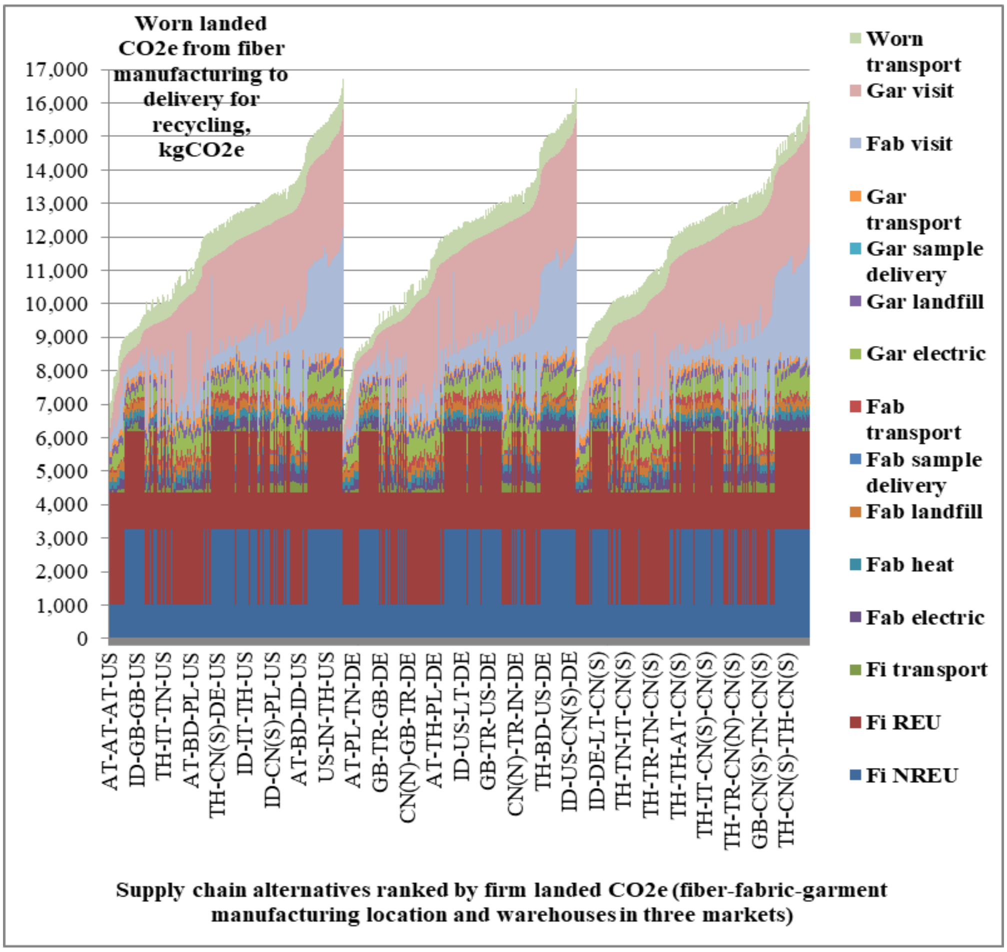

Figure 3.13 Carbon dioxide equivalent (CO2e)-factor graph plotting of all 4,608 alternatives with three markets showing 1,800 t-shirt worn CO2e of all alternatives ranked by firm CO2e.

Remarks: Only some alternative names are shown; Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, NREU= non-renewable energy use, REU= renewable energy use; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, TH= Thailand, DE= Germany, IT= Italy, PL= Poland, LT= Lithuania, TN= Tunisia, EG= Egypt, TR= Turkey, CN(S)= China (Shanghai), BD= Bangladesh, IN= India.

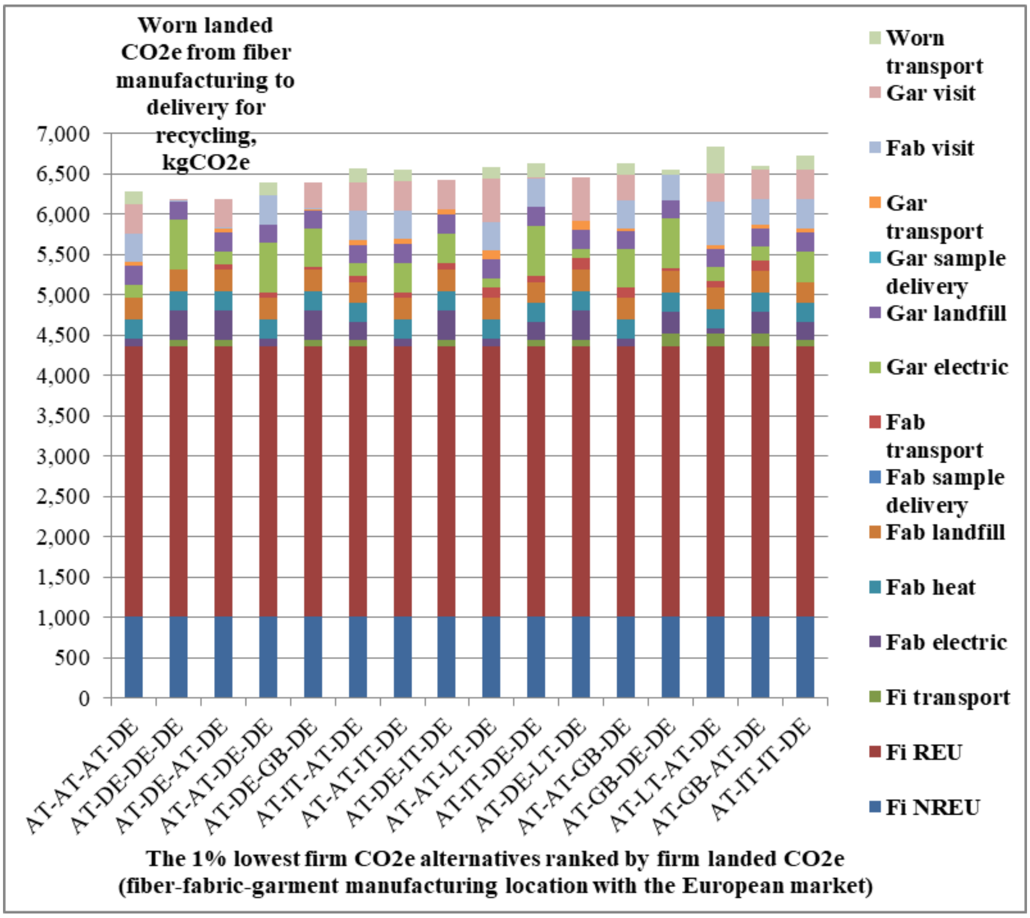

Figure 3.14 Carbon dioxide equivalent (CO2e)-factor graph plotting of 1,800 t-shirt worn CO2e ranked by the 1% lowest firm CO2e alternatives with the warehouse in Germany.

Remarks: Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, NREU= non-renewable energy use, REU= renewable energy use; AT= Austria, GB= Great Britain, DE= Germany, IT= Italy, LT= Lithuania.

3.4.5 Step 11: Supply Chain Selection

For the supply chain selection, users can see the lowest cost and CO2e supply chains for all three markets from Figure 3.5 to Figure 3.10. Users can further conduct cross tabulation among results of different markets and computational scopes according to their objectives. As the objective of this model application is to find the optimized cost and CO2e supply chains, scatter plotting between firm cost and CO2e is used. An example of the scatter plot for the US market is as shown in Figure 3.15. The other-market scatter plots are shown in

Figure E.5 and Figure E.6 in Appendix E. The scatter plots of all three markets show similar plotting results especially results of the low cost and CO2e alternatives. It is noticeable that the Pareto frontier alternatives and low cost/CO2e alternatives have either European or African fabric and garment manufacturing.

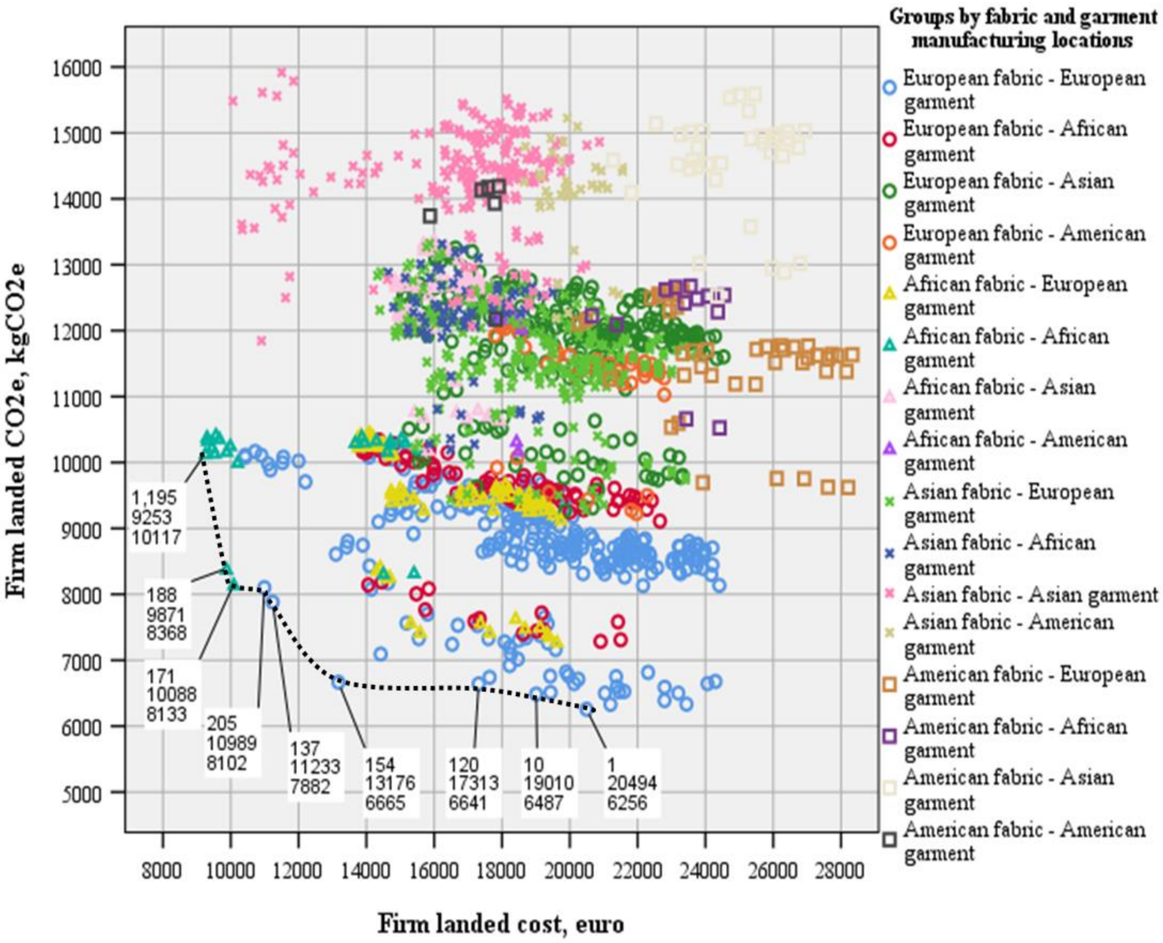

Figure 3.15 Firm cost and carbon dioxide equivalents (CO2e) scatter plotting of alternatives with the warehouse in the United States for one batch of 1,800 t-shirt manufacturing.

Remarks: Pareto frontier alternatives are shown with information of their alternative numbers, costs, and CO2e from top to bottom; Alternative numbers and fiber, fabric, and garment manufacturing locations are 1195 (US-TN-TN), 188 (AT-EG-EG), 171 (AT-TN-TN), 205 (AT-TR-TR), 137 (AT-PL-PL), 154 (AT-LT-LT), 120 (AT-IT-IT), 10 (AT-AT-LT), and 1 (AT-AT-AT); AT= Austria, US= the United States, IT= Italy, PL= Poland, LT= Lithuania, TN= Tunisia, EG= Egypt, TR= Turkey.

By using cross tabulation, common Pareto frontier alternatives of all three markets are revealed in Table 3.15. The Pareto alternatives have fibers mainly from Austria and fabrics and garment manufacturing in Europe and Africa. Users can select the common Pareto frontier alternatives for designing the product supply chain according to cost and CO2e constraints and goals. Moreover, if there is a CO2e constraint at 10,000 kgCO2e, users can pay attention to the supply chains with European and African fabric and garment manufacturing. Surprisingly, low-cost distant manufacturing in Asian countries are not locations of the Pareto frontier alternatives and the alternatives with Asian garment manufacturing locations are far from the Pareto frontier.

Table 3.15 Pareto frontier alternatives as well as their costs and carbon dioxide equivalent (CO2e) for one batch of 1,800 t-shirt manufacturing.

Warehouse locations	US		DE		CN	
Fiber-fabric-garment manufacturing locations	Firm cost	Firm CO2e	Firm cost	Firm CO2e	Firm cost	Firm CO2e
US-EG-EG	-	-	7,768	10,296	8,505	10,375
ID-EG-EG	-	-	7,777	10,245	8,515	10,324
US-TN-TN	9,253	10,117	7,921	10,041	8,660	10,162
AT-EG-EG	9,871	8,368	8,215	8,291	9,030	8,370
AT-TN-TN	10,088	8,133	8,572	8,056	9,425	8,177
AT-TR-TR	10,989	8,102	-	-	10,048	8,119
AT-PL-PL	11,233	7,882	8,685	7,791	10,540	7,990
AT-LT-LT	13,176	6,665	10,325	6,616	12,377	6,774
AT-IT-IT	17,313	6,641	13,392	6,548	15,929	6,694
AT-AT-LT	19,010	6,487	15,387	6,438	17,928	6,596
AT-AT-AT	20,494	6,256	15,867	6,122	18,827	6,288

Remarks: AT= Austria, ID= Indonesia, US= the United States, DE= Germany, IT= Italy, PL= Poland, LT= Lithuania, TN= Tunisia, EG= Egypt, TR= Turkey, CN= China (Shanghai).

3.4.6 Step 12: Result Robustness Check and Risk Identifications by Sensitivity Analysis

Sensitivity analysis is used to see important factors and different contexts and environments influencing low cost and CO2e supply chains for possible disruptive risks in the future. I will focus on new lowest cost/CO2e alternatives which replace the lowest cost/CO2e alternatives from the base-case scenario shown in Table 3.16. Factor values are changed within 25% by decreasing and increasing factor coefficients at 0.75 and 1.25 in order to see how decreasing and increasing factor values affect the lowest cost/CO2e alternatives.

Table 3.16 The lowest cost and carbon dioxide equivalent (CO2e) alternatives and their values of all investigated markets and computational scopes from the base case.

Ware-	Cost computational scopes						CO2e computational scopes					
house	Landed	euro	Firm	euro	Worn	euro	Landed	kgCO2e	Firm	kgCO2e	Worn	kgCO2e
US	ID-ID-ID	5,078	US-TN-TN	9,253	US-TN-TN	11,180	AT-AT-AT	5,543	AT-AT-AT	6,256	AT-DE-DE	6,721
DE	ID-ID-ID	4,025	US-EG-EG	7,768	US-EG-EG	9,229	AT-AT-AT	5,408	AT-AT-AT	6,122	AT-DE-DE	6,190
CN(S)	ID-ID-ID	3,668	US-EG-EG	8,505	ID-ID-ID	10,080	AT-AT-AT	5,574	AT-AT-AT	6,288	AT-AT-AT	6,902

Remarks: AT= Austria, ID= Indonesia, US= the United States, DE= Germany, TN= Tunisia, EG= Egypt, CN= China (Shanghai).

3.4.6.1 Changing Manufacturing-Related Factor

Changing manufacturing-related factors show that the results of the lowest cost and CO2e supply chains are stable especially for the firm and worn scope. The only effect is on the German landed cost computational scope from decreasing productivity (at 0.75). The new alternative is CN(N)-BD-BD (Chinese fiber with fabric and garment manufacturing in Bangladesh) instead of ID-ID-ID (agglomerative/vertical manufacturing from fiber to garment in Indonesia) for the base-case alternative. Increasing and decreasing the amount of solid waste into landfills, the percentage of factory overhead expenses and profits, and interest rate for headquarter do not change the lowest value alternatives. Additionally, the lowest CO2e alternatives of all markets and computational scopes do not get affected from the manufacturing-related factor changes.

3.4.6.2 Changing Each Cost Factor in All Locations and Each Location at a Time

The cost factors to be varied involve manufacturing, logistics, and sustainability assurance activities. By varying each cost factor in all locations at a time, only seven factors change the lowest cost alternatives of the firm scope for all three markets and of all computational scopes of the European market. The results are shown in Table E.3 in Appendix E. Other administrative wages, electricity fee, wood price for heating boiler, solid waste management fee, rent, employee costs for certificate implementation at fabric and garment factories, fabric lab test, fabric and garment sample delivery, and hotel cost for visiting factories are not sensitive factors because they do not give new lowest-cost alternatives.

By changing values of each manufacturing-cost factor in each location at a time, the sensitive cost factors and their coefficients which make new lowest cost alternatives are shown in Table E.4 and Table E.5 in Appendix E for manufacturing and firm related cost factors, respectively. The Asian market landed cost computational scope does not get affected by the changes. Furthermore, other administrative wages, wood price for heating boiler, solid waste management fee, rent, employee costs for certificate implementation at garment factories, fabric and garment sample delivery, and hotel cost for visiting factories are not sensitive factors.

Changing values of logistics costs relating to ship and truck cost rates and duty fees are shown in Table E.6 and Table E.7 in Appendix E. The tables do not show CN landed cost computational scope for Asian market because it does not get affected by any changes. Changing truck cost rates and duty fees of fiber, fabric, and worn garments in all locations as well as from and to each location do not change their lowest cost alternatives.

3.4.6.3 Changing Each CO2e Factor in all Locations and Each Location at a Time

Sensitivity analysis for CO2e is done by changing CO2, CH4, and N2O EFs as well as CO2e of all CO2e factors with 0.75 and 1.25 coefficients. The results show that changing CO2, CH4, and N2O EFs of NRUE (anthracite), REU (wood), landfill gas, and passenger cars as well as changing CO2e from fabric and garment sample delivery from all locations, and flight for visiting factories in each location excepting Austria do not generate any new lowest CO2e alternatives. Therefore, they are not sensitive/risk factors. Changing CH4 and N2O EFs of road vehicle (truck) and watercraft (ship) do not also generate any new lowest CO2e alternatives unlike changing their CO2 EFs as shown in Table E.8 in Appendix E. It is interesting to see that the new lowest alternatives are similar to the base-case lowest CO2e alternatives by consisting of Germany and Austria as fabric and garment manufacturing locations with Austria fiber manufacturing. These can also be found in the other new lowest CO2e alternatives generated by changing flight CO2e for visiting factories in all locations at a time and for visiting Austrian factories shown in Table E.8. Moreover, there is no new lowest CO2e alternative for all market landed CO2e scopes and CN worn CO2e scope.

In summary, all sensitivity results by varying cost and CO2e factors confirm that the model gives relatively robust results. It can be concluded that the lowest and 1% lowest cost and CO2e alternatives are resistant to changing environments as only some factors change the lowest cost and CO2e alternatives of some markets and computational scopes. Moreover, the new lowest cost and CO2e alternatives are originally competitive alternatives to be considered as potentially selected supply chains because most of the new alternatives were the second and third lowest cost and CO2e alternatives. Only few are from other ranks but still within the 11^{th} lowest cost and CO2e ranking out of 1,536 alternatives.

3.4.7 Step 12: Result Robustness Check and Risk Identifications by Scenario Analysis

Current trade war among countries and the results from Step 10 showing high CO2e from fiber manufacturing and sustainability assurance activities highly affecting costs and CO2e lead to scenario analysis. I investigate different scenarios by changing duty fees of fibers, fabrics, garments, and worn garments, by assuming different fiber manufacturing technology at each location, and by assigning costs and CO2e from the sustainability assurance activities into different number of manufacturing batches. The different number of batches can refer to different product types whether they are required high level of control from headquarters to visit factories often as well as whether they are basic, repetitive ordering, or good-sale reordering products.

3.4.7.1 Duty Fee Scenario Analysis for Trade War Imitation

For scenario analysis of duty fees, I assume that the trade war situation leads every country to compete one another by decreasing and increasing duty fees to be at the same fees as competitive countries. Therefore, all fiber, fabric, garment, and worn garment duty fees from everywhere are set to be equal at zero, 5, 10, 20, 30, and 40 percentages as shown in Table E.9 in Appendix E. Assigning the equal duty fees to all locations do not generate new lowest cost alternatives of DE firm and worn cost computational scopes and of CN landed cost computational scopes. Moreover, the results of duty fee scenario analysis (Table E.9) reveal that low-cost manufacturing locations become competitive for European and Asian markets when garment duty fees increases and high import duty fees cannot create competitiveness for relative higher cost manufacturing in the local markets. On the other hand, local US manufacturing especially garment manufacturing become competitive as the lowest cost alternative after increasing garment duty. Furthermore, scenario analysis shows that the results of firm and worn computational scope for the German warehouse as well as landed computational scope for the Chinese warehouse are highly resistant to the changed scenarios. The other results excepting the results for the US warehouse shows high resistant to the changed duty scenarios because the new lowest cost alternatives were the second and third lowest cost alternative of the base-case scenario. Additionally, I stop at 40 percent due to the maximum existing duty fee. Different or higher percentages can be used according to product types and users' analysis requirements.

3.4.7.2 Fiber Manufacturing Technology Scenario Analysis

According to the results from Step 10 that NREU and REU CO2e from fiber manufacturing are important factors, I changed NREU and REU coefficients for turning Austrian fiber manufacturing to have no longer clean technology (NREU coefficient as 3.211 and REU coefficient as 0.882) and for turning the other fiber manufacturing locations to have clean technology as Austria (NREU coefficient as 0.311 and REU coefficient as 1.134). Both scenarios show the same results of three new lowest CO2e alternatives: GB-LT-LT for US landed scope replacing AT-AT-AT, GB-DE-DE for US worn scope replacing AT-DE-DE, and GB-DE-DE for DE worn scope replacing AT-DE-DE. The results show that the firm scope has stable unchanged results while the landed and worn scopes reveal that Great Britain will be a competitive low-CO2e fiber manufacturing location to Austria if its location implements clean manufacturing technology.

3.4.7.3 Manufacturing Batches Scenario Analysis

Some products such as t-shirts can be produced repetitively over a period of time and require little control for repeated manufacturing batches. Therefore, I set the scenario of manufacturing 6, 12, and 18 batches of 1,800 t-shirts. When varying the number of manufacturing batches, costs and CO2e from sustainability assurance activities are changed. Costs and CO2e of fabric and garment sample delivery and transportation of managers to visit factories, as well as costs of fabric sample lab test, and manager and hotel during factory visits are assigned to several batches leading to decreased costs and CO2e of each batch and some new lowest cost and CO2e alternatives as shown in Table 3.17.

Table 3.17 Scenario analysis results showing new lowest cost/CO2e alternatives and their decreased values after changing the number of manufacturing batches to be 6, 12, and 18 batches for three warehouses and three computational scopes.

Number of batch	Ware-house	Cost computational scopes						CO2e computational scopes					
		Landed	euro	Firm	euro	Worn	euro	Landed	kgCO2e	Firm	kgCO2e	Worn	kgCO2e
1 (base case)	US	ID-ID-ID	-	US-TN-TN	-	US-TN-TN	-	AT-AT-AT	-	AT-AT-AT	-	AT-DE-DE	-
	DE	ID-ID-ID	-	US-EG-EG	-	US-EG-EG	-	AT-AT-AT	-	AT-AT-AT	-	AT-DE-DE	-
	CN(S)	ID-ID-ID	-	US-EG-EG	-	ID-ID-ID	-	AT-AT-AT	-	AT-AT-AT	-	AT-AT-AT	-
6	US	-	-122	ID-ID-ID	-3,438	-	-3,209	-	-0.43	-	-595	AT-AT-AT	-533
	DE	-	-104	-	-3,052	-	-3,052	-	-0.43	-	-595	AT-AT-AT	-511
	CN(S)	-	-95	ID-ID-ID	-4,091	-	-4,217	-	-0.43	-	-595	-	-595
12	US	-	-134	ID-ID-ID	-3,863	-	-3,530	-	-0.47	-	-654	AT-AT-AT	-592
	DE	-	-115	ID-ID-ID	-3,422	-	-3,357	-	-0.47	-	-654	AT-AT-AT	-570
	CN(S)	-	-105	ID-ID-ID	-4,513	-	-4,639	-	-0.47	-	-654	-	-654
18	US	-	-138	ID-ID-ID	-4,004	-	-3,636	-	-0.48	-	-674	AT-AT-AT	-612
	DE	-	-118	ID-ID-ID	-3,562	-	-3,459	-	-0.48	-	-674	AT-AT-AT	-590
	CN(S)	-	-108	ID-ID-ID	-4,653	-	-4,779	-	-0.48	-	-674	-	-674

Remarks: AT= Austria, ID= Indonesia, US= the United States, DE= Germany, TN= Tunisia, EG= Egypt, TR= Turkey, CN(S)= China (Shanghai); and the cost and CO2e of the base-case alternatives are in Table 3.16.

It can be seen that the new alternatives have agglomeration of fiber, fabric, and garment manufacturing locations (highly-vertical manufacturing). After increasing manufacturing batches, the firm cost computation scope yield the same lowest cost alternatives as the landed cost computation scope. However, the decreased cost of sustainability assurance activities cannot change the result of the worn cost computation scope. This implies that reverse logistics costs have more influence on total costs than sustainability assurance costs for closed-loop supply chains. Regarding CO2e, the results imply that fiber manufacturing technology have high impact on all computational scopes.

Due to the changes of both cost and CO2e from varying the number of manufacturing batches, I repeated Step 11 for scatter plotting in order to show tradeoff between cost and CO2e among different number of batches shown in Figure 3.16. Figure 3.16 illustrates that the more manufacturing batches to which costs and CO2e of sustainability assurance activities are assigned, the less cost and CO2e of all supply chain alternatives (by shifting towards lower left of the plots) and the more CO2e competitiveness among all alternatives (by less scattering and gap between the lowest and highest CO2e on the y-axis). This leads to the fact that some Asian manufacturing alternatives, which are the pink crosses (x) in Figure 3.16, become Pareto alternatives. Figure 3.16 also illustrates the cost and CO2e similarities among 6-, 12-, and 18 manufacturing batches. Their similarities reveal that the higher number of manufacturing batches, the less effect of sustainability assurance activities on cost and CO2e. Additionally, the other two warehouses in Germany and China also show similar scattering plots and results to the warehouse in US shown in Figure 3.16.

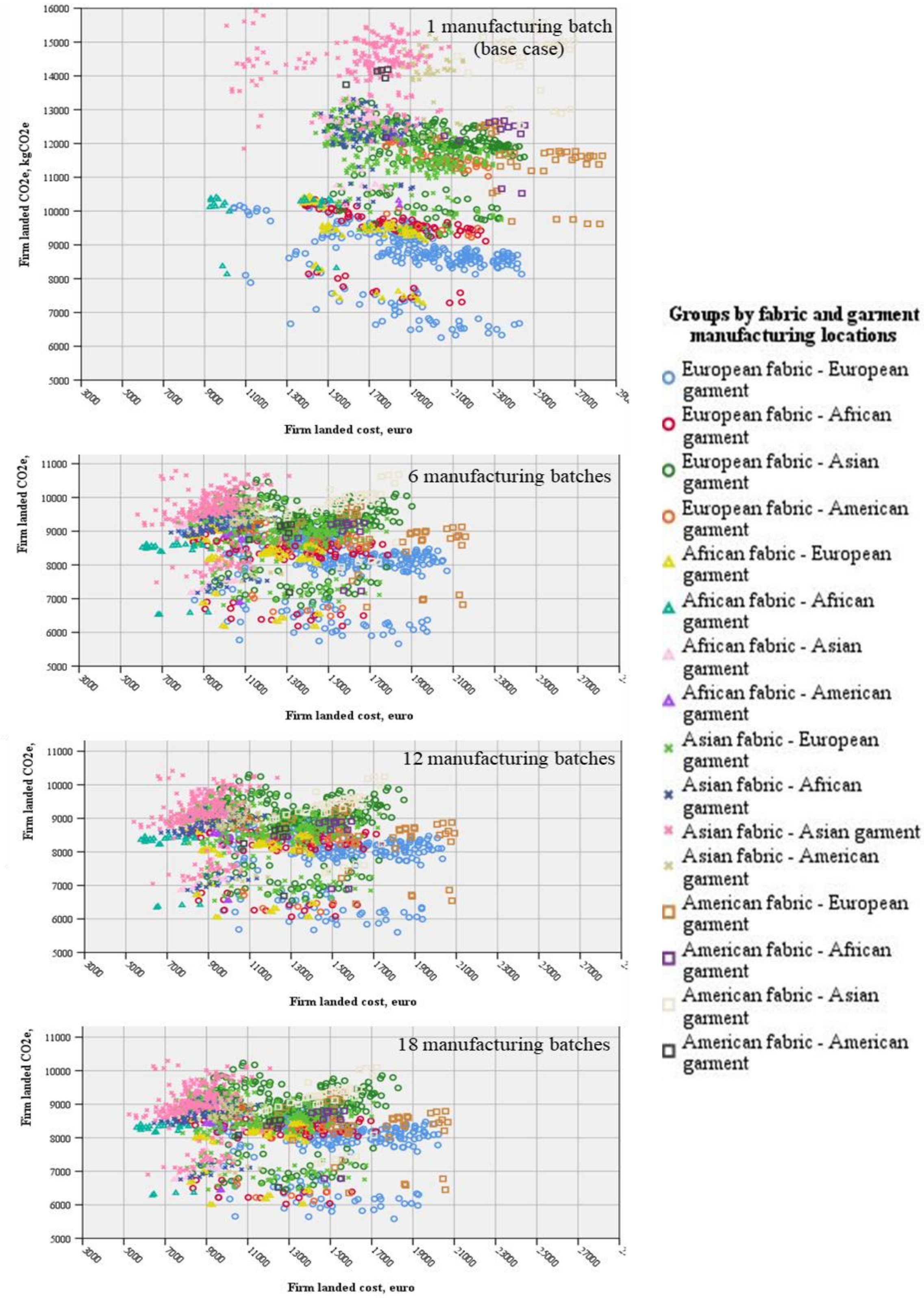

Figure 3.16 Comparison of 1-, 6-, 12-, and 18-manufacturing batch scatter plots of firm costs and carbon dioxide equivalent emissions (CO2e) for the warehouse in the United States.

I used the cross tabulation technique to find common supply chains among Pareto frontier alternatives of 1-, 6-, 12-, and 18-manufaturing batches as shown in Table 3.18 as an example from supply chains with the US warehouse. The results of the other warehouses show similar results. Table 3.18 presents five common Pareto supply chains with Austrian or US fiber and fabric and garment manufacturing in Europe or Africa. The five supply chains are highly resistant to different number of manufacturing batches implying different control level from sustainability assurance activities.

Table 3.18 Pareto frontier alternatives of the United States warehouse showing firm cost and carbon dioxide equivalent (CO2e) per a 1,800 t-shirt batch under different manufacturing batches.

Supply chain	1 batch		6 batches		12 batches		18 batches	
	Cost	CO2e	Cost	CO2e	Cost	CO2e	Cost	CO2e
AT-AT-AT	**20,494**	**6,256**	**18,368**	**5,661**	**18,156**	**5,602**	**18,085**	**5,582**
AT-AT-LT	**19,010**	**6,487**	**14,547**	**5,744**	**14,101**	**5,670**	**13,952**	**5,645**
AT-IT-IT	17,313	6,641						
AT-LT-LT	**13,176**	**6,665**	**10,717**	**5,774**	**10,471**	**5,685**	**10,389**	**5,656**
AT-TN-LT	-	-	10,036	6,163	9,481	6,038	9,296	5,997
AT-PL-PL	11,233	7,882	-	-	-	-	-	-
AT-TR-TR	10,989	8,102	-	-	-	-	-	-
AT-TN-TN	10,088	8,133	-	-	-	-	-	-
AT-EG-LT	-	-	9,888	6,188	9,346	6,051	9,165	6,005
AT-EG-EG	**9,871**	**8,368**	**6,792**	**6,526**	**6,485**	**6,342**	**6,382**	**6,280**
AT-BD-BD	-	-	6,720	7,484	6,301	7,048	6,162	6,902
ID-EG-EG	-	-	6,231	8,480	5,923	8,296	5,820	8,234
US-EG-EG	-	-	-	-	5,912	8,347	5,809	8,286
US-TN-TN	**9,253**	**10,117**	**6,044**	**8,516**	**5,724**	**8,356**	**5,617**	**8,303**
ID-BD-BD	-	-	-	-	-	-	5,600	8,590
CN(N)-BD-BD	-	-	-	-	5,718	8,813	5,579	8,667
ID-ID-ID	-	-	5,815	9,495	5,391	8,896	5,249	8,697

Remarks: AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, US= the United States, PL= Poland, IT= Italy, LT= Lithuania, TN= Tunisia, EG= Egypt, TR= Turkey, BD= Bangladesh; and bold indicates common supply chains among different manufacturing batches.

In Table 3.18, it can be seen that the five common optimized cost and CO2e supply chains have variations of cost and CO2e; therefore, users can select a supply chain that meet their cost and CO2e preferences and constraints. For example, if users prefer low CO2e supply chains with a cost constraint at 10,000 euros, the chose supply chain will be AT-EG-EG which is using Austrian fibers to produce fabrics and t-shirts in Egypt. Though US-TN-TN has lower cost than AT-EG-EG, US-TN-TN has much higher CO2e. Moreover, using fiber from the locations in proximity to the fabric and garment manufacturing locations helps reduce risks from transportation such as delay and loss. Additionally, Asian fabric and garment manufacturing become competitive after increasing the number of manufacturing batches as shown in Table 3.18 that after the batch number increase, there are new Pareto alternatives which are three supply chains with fabric and garment manufacturing in Bangladesh and one supply chain with highly-integrated manufacturing in Indonesia.

3.4.8 Conclusion and Implications

Specifically to the viscos t-shirt supply chain with the business headquarter in Germany, the most economical supply locations are using the United States (US) fibers to produce fabric and garment at the agglomerative locations in African countries: Egypt (US-EG-EG) for the warehouses in Germany and China (Shanghai) and Tunisia (US-TN-TN) for the warehouse in the United States. However, if considering a closed-loop supply chain to send worn garments back to fabric factories for recycling, the agglomeration of fiber, fabric, and garment manufacturing (highly integrated production) in Indonesian (ID-ID-ID) is the most economical supply chain for the warehouse in China while the alternatives for the other warehouses are unchanged.

In terms of CO2e, the most eco-friendly supply chains are the agglomeration of fiber, fabric, and garment manufacturing in Austria (AT-AT-AT) for all three warehouses and for only the warehouse in China when considering the closed-loop supply chain. For the closed-loop supply chain, Austrian fiber with the agglomeration between fabric and garment manufacturing in Germany (AT-DE-DE) is the most eco-friendly alternative for warehouses in Germany and the United States. The results highlight the importance of clean manufacturing technology to make low CO2e supply chains because in the base case of this model application, only Austrian fiber manufacturing has implemented clean manufacturing technology. However, when setting all fiber manufacturing locations to have the same clean and unclean technology, British fiber manufacturing gives the lowest CO2e alternatives. Furthermore, some of the previous-mentioned lowest value alternatives, which are US-TN-TN and AT-AT-AT, are the Pareto (cost-CO2e efficient) alternatives for all three warehouses when considering the firm computational scope. Therefore, if users cannot split production for different markets and have to deliver finished products directly to warehouses in Germany, China, and the United States, they can choose one of the two alternatives according to their cost and CO2e constraints and goals. Moreover, if there are only warehouses in Germany and China, US-EG-EG is an additional alternative to be chosen. Additionally, users can use the model to do feasibility analysis for splitting production into different locations for different markets by adding new locations near to the markets into the model.

Regarding agglomeration among supply chain stages, agglomeration between fabric and garment manufacturing locations especially in Egypt and Tunisia has high potentials to generate low cost alternatives for all three warehouses. For CO2e, agglomeration between fiber and fabric, fabric and garment, fabric and firm, garment and firm especially in Austria and Germany show similar potentials to generate low CO2e alternatives for all warehouses.

The most important cost and CO2e factors relate to firm's sustainability assurance to visit factories for checking product quality as well as environmental practices and social compliances. Moreover, the other crucial CO2e factors relate to energy use in fiber manufacturing. When using sensitivity analysis to check the result robustness and possible disruptive events, the results show that the model can provide robust results of the 1% lowest cost and CO2e alternatives. Fabric and garment agglomerative manufacturing locations of the new lowest cost alternatives are still in in Egypt followed by in Tunisia with other fiber locations especially Indonesia which is also a new fabric and garment agglomerative manufacturing location. On the other hand, the fiber manufacturing location of the new lowest CO2e alternative remain in Austria with the same continent of fabric and garment agglomerative manufacturing location in Germany rather than in Austria. Additionally, the new lowest cost alternatives are from changing fiber price, wages, and firm transportation and employee costs for factory visits as well as ship transportation price and garment duty while the new lowest CO2e alternative is from changing CO2e of flight to visit factories.

For scenario analysis, the results of the trade war scenario by increasing duty fees of all locations show that 10 percent increased garment duty fees affects the lowest firm cost alternatives of supply chains with warehouses in the United States and China. Their new lowest firm cost alternatives are fiber, fabric, and garment manufacturing agglomeration in US and Indonesia, respectively. The scenario analysis results of having the same technologies (CO2e) of fiber manufacturing in all locations show that the firm CO2e alternative is unchanged implying the robustness of the lowest CO2e alternative. For the scenario analysis of different number of manufacturing batches, the more manufacturing batches, the less supply chain costs and CO2e as well as the more CO2e competitiveness among all alternatives. Moreover, increasing number of manufacturing batches generates additional Pareto efficient alternatives and some of them have fabric and garment manufacturing in Asia implying that Asian fabric and garment manufacturing are competitive locations for repeated manufacturing products.

4 Discussions, Conclusions and Contributions

The main research questions (RQs) of this thesis are RQ 1 and RQ 2 will be answered by results of Study 1 to Study 3 with RQ 3 to RQ 8 and of reviewing the other existing studies in Chapter 1. Therefore, I start this section by summarizing Study 1 to Study 3 followed by discussions for answering RQ 1 and RQ 2. The section will be ended with theoretical contribution, research limitation, and future research directions as well as practical and social implications and contributions.

4.1 Summary on Study 1-3 Answering Research Questions 3-8

The systematic literature review (SLR) results from content analysis show high number of business benefits leading to four inductive business subgroups: profits (cost-price-sale), service and delivery, product quality, as well as product and process development and innovation. The benefits were extracted from primary studies which were selected by inclusion and exclusion criteria from searched peer-reviewed articles on Scopus and Web of Sciences databases in 2016. Different studied markets of the 45 primary studies present common and different benefits of proximity manufacturing across times answering research question (RQ) 3: What are proximity-manufacturing benefits of the textile and clothing industry in each market location under each TBL dimension?. Most environmental factors relating to gas emissions seem to be important to the European market and undermined in the Asian market which focuses on job creation and economic growth as social/socio-economic factors. However, the Asian market still lacks the governmental support on social compliances and benefits. The SLR findings present the potentials of governments in every continent to support proximity manufacturing in terms of trade policies, finance, logistical infrastructure, worker training, production knowledge and business alliances, as well as environmental and social-related laws and regulations in order to enhance TBL sustainability. Regarding RQ 4: How has proximity manufacturing for the textile and clothing industry been studied across time in terms of methods, studied contexts (product and market locations), and TBL dimensions?, the findings show the lack of studies on all TBL and the environmental dimension, on the African and Oceania markets, and using mixed-method. The common method is qualitative approach with interviews as primary data collection but there is a trend of quantitative approach with modelling. This finding confirms the potential of the selected methods to be used in the subsequent studies to answer the main RQs of the thesis. Additionally, regarding the relationship between production and market locations, the findings from SLR show that local manufacturing for the proximity to low-cost market manufacturing implies domestic manufacturing and for the proximity to high-cost market manufacturing implies nearshoring manufacturing. In 2020, I conducted another SLR in order to see how recent studies have mentioned proximity manufacturing benefits. The results of the additional SLR show similar proximity benefits to the previous SLR with higher focuses on sustainable production and consumption from studies relating to slow fashion, circular economy, and reshoring. Moreover, there are significant increases of studies mentioning all TBL benefits.

As the first SLR hardly revealed environmental and social/socio-economic benefits (positive factors) of proximity manufacturing, semi-structured interviews of managers from twelve clothing companies were conducted in order to reveal and update TBL factors and reasons of proximity and distant manufacturing locations. The SLR findings provide guidance to this qualitative interview study on methods, coding scheme formulation, and data collection and analyses. The interviewed data were triangulated with shop and showroom visiting, materials given by the interviewees, and online data on company websites including financial and sustainability reports. With within- and cross-case analyses, the interviews reveal both common and different benefits of proximity and distant manufacturing to/from existing studies answering RQ 5: Why and in which business contexts do managers choose proximity manufacturing over distant manufacturing? and RQ 6: Why and in which business contexts do managers choose distant manufacturing over proximity manufacturing?. The discovered reasons and benefits of proximity manufacturing differentiating from existing studies are garment cost structure between material and labor costs, short travelling for price and style discussion, and European chemical laws for social compliance, and product innovation. On the other hand, the discovered distant-manufacturing reasons and benefits, which are barriers to proximity manufacturing, are company's inability to find European manufacturers, existing distant suppliers with good collaboration, local representatives at manufacturing locations, the lack of recycling infrastructure and laws, and manager concerns on high costs of living in Europe for seamstresses' salaries. Moreover, some proximity and distant manufacturing reasons and benefits are common factors of proximity and distant manufacturing and they can be positive or negative factors to proximity and distant manufacturing. The common factors include the proximity between fabric and garment manufacturers, good relationship and collaboration with existing manufacturers, the access to high-quality and vertical manufacturers, political risks, trade policies, and environmental laws and regulations. The interview findings also reveal that factors of manufacturing location decisions are influenced by business contexts which include company's strategies, resources, and capabilities as well as external environments, government, and suppliers. The validity of the thesis findings is significantly enhanced by this study which allows me identify patterns of results among proximity and distant manufacturing and results from SLR and to understand what contexts cause the results (Yvonne Feilzer, 2009). Additionally, this study reveals that proximity manufacturing can be proximity to markets, to headquarter, and to suppliers as well as within the country as domestic manufacturing or in nearby countries as nearshoring manufacturing either in the same or adjacent continents.

The findings from literature reviews and interviews help formulate the proposed model for designing multi-tier supply locations for sustainable product supply chains as well as provide input factors to the model application whose results are feedback to upgrade previous-versions of the model. The model helps users to design multi-tier supply locations to enhance sustainable product supply chains by revealing top performance low cost and CO2e alternatives, their supply chain types in terms of supply chain stage agglomeration and proximity, and their important factors for different markets and computational scopes. Therefore, the model helps answer RQ 7: Which manufacturing location decisions make low cost and/or CO2e supply chains for different markets and computational scope? and RQ 8: What are cost and CO2e factors highly influencing the lowest cost and CO2e supply chains?. The model uses cost and carbon dioxide equivalent (CO2e) from greenhouse gas emissions as proxies to measure and compare supply chain performances of all alternatives. The cost and CO2e calculation includes manufacturing, logistics, and firm's sustainability assurance activities in all supply chain stages. Though there is no social measurement, the model ensures the social sustainability and the environmental sustainability by taking into account all activities relating to good social and environmental practices such as paying living wages, sending fabrics to laboratory for chemicals testing, implementing certificates, and visiting factors for checking environmental and social practices. At the end, the model application in textile and clothing industries show both lowest and optimized/efficient cost and CO2e supply chains as well as important factors by using exploratory analysis techniques suggested by the proposed model. Exploratory analysis techniques include alternative ranking, cross tabulation, 2-D stacked column plotting, and scatter plotting. The result robustness and its resistance to changed environments as well as possible risks from global and local disruptive events are investigated by sensitivity and scenario analysis. The model shows robust results after performing sensitivity analysis. The scenario analysis reveals the importance of identifying product types and business contexts benefiting the allocation of sustainability-related costs to one or several batches. The last but not least, the model results show the necessity to consider cost and CO2e from firm sustainability assurance activities for forward supply chains and reverse logistics for closed-loop supply chains because they significantly increase total cost and CO2e as well as make some supply chains no longer be the 1% lowest cost and CO2e supply chains.

4.2 Answers to Research Question 1 of the Thesis

Study 1, Study 2, Study 3.1, and Study 3.2 help achieve the research aims on knowing whether proximity or distant manufacturing yields a relatively better supply chain in terms of enhancing TBL and on developing a manufacturing location decision-support model with TBL factors and objective performance measures to achieve sustainable multi-tier supply chains. Studying both proximity and distant manufacturing with different methods help answer RQ1: How do different manufacturing location decisions enhance TBL? Different methods include SLRs, semi-structured interviews of manufacturing decision makers from twelve Swedish clothing retailers, and supply chain simulations with a model formulation and application in designing a viscose t-shirt supply chain. Benefits of proximity and distant manufacturing locations to each TBL have been revealed.

The thesis findings show that benefits of proximity manufacturing are from spatial, cultural, and linguistic proximity among stakeholders in different supply chain stages including materials manufacturers, product manufacturers, headquarters, and consumers. As this thesis shows common and unique proximity-manufacturing benefits among different studied markets by SLRs and common benefits of proximity and distant manufacturing by interviews and simulations, I found out that proximity-manufacturing benefits and manufacturing location decisions depend on country-specific advantages (Rugman et al., 2012). The advantages are from legal framework, governmental supports, industrial infrastructure, suppliers, demand, support from local society and organizations. As a result, I categorized TBL benefits from this thesis into Table 4.1 and Table 4.2. Table 4.1 presents TBL benefits from spatial, cultural and linguistic proximity among supply chain stakeholders while Table 4.2 presents TBL benefits from country, supplier, and firm specific advantages.

Table 4.1 and Table 4.2 help answer RQ 1 by showing the fact that different manufacturing location decisions on either proximity or distant manufacturing will gain TBL benefits from different kinds of proximity and country-, supplier-, and firm- specific advantages from chosen locations. It can be seen that TBL benefits in Table 4.1 and Table 4.2 involve factor conditions, demand conditions, supporting industries, and firm strategy of the Porter's (1990) diamond framework. The reasons could be that firms seek competitiveness from not only proximity benefits but also benefits from manufacturing countries, suppliers, and their own resources.

Table 4.1 leads to the potentials of different kinds of proximity manufacturing, which include proximity manufacturing to markets, materials sources, and headquarters, to give TBL benefits. The proximity between headquarters and other supply chain stakeholders and environmental and socio-economic benefits are additional aspects which are not mentioned by Weber (1929)'s theory on industrial location decisions.

Table 4.1 Triple bottom line benefits from spatial, cultural, ethnic and linguistic proximity among supply chain stakeholders.

Sources of benefits	Business benefits	Environmental benefits	Socio-economic benefits
Spatial proximity of manufacturing to the market	Lower duties, lower logistics costs, postpone production, licensed products, lower total costs from lower inventory and leftovers from better forecasting, ability to know local tastes and trend for product design, short lead time, fast replenishment and timely inventory, ability to offer high-service level with customized products, quick response to uncertain demand, gaining consumers' awareness and preference on local products, lower costs of sending used products to recycling manufacturers	Lower gas emissions from product and sample transportation, better forecasting lead to lower wastes from leftovers and resource consumption	Possibilities to creating social inclusion, interaction, and pride in society from local initiatives relating proximity manufacturing
Spatial proximity of manufacturing to the materials source	Lower duties, lower logistics costs, postpone production, lower inventory costs, short lead time, supply chain efficiency, knowledge spillovers	Lower gas emissions from product and sample transportation	
Spatial proximity of manufacturing to headquarters	Lower costs of coordination and sustainability assurance activities, avoid currency risks, avoid reputation risks, short lead time for sample delivery, fast prototype development, maintaining in-house competence, and the easiness to visit manufacturers for style and price discussion, operational control, problem solving, being presence, quick sample development, operations and product inspection and control	Lower gas emissions from manager transportation, the easiness to visit factories for assuring environmental compliance	The easiness to visit factories for ensuring non-hazardous chemicals in operations and products and good social compliances
Spatial proximity of headquarters to the market	Avoid currency risks, ability to know local tastes and trend for product design, quick prototype testing		
Cultural, ethnic, and linguistic proximity between headquarters and suppliers	Lower total costs, smooth operations, quick sample development from understanding what companies want, business support from the same ethnic		Trust suppliers to follow social compliances

Table 4.2 Triple bottom line benefits from country, supplier, and firm specific advantages.

Sources of benefits	Business benefits	Environmental benefits	Socio-economic benefits
Country specific advantages	Lower duties, licensed products, lower total costs, avoid political risks, availability and quality of materials and material suppliers, existence of industrial set up and workforce, low labor costs from domestic or nearshoring manufacturing, emerging markets, logistical infrastructure, demand on local and sustainable products[1] and willingness to pay more, supply chain efficiency from industrial clusters, tacit knowledge in society, knowledge and resource sharing among proximity manufacturing networks and local clusters, governmental support on tax, finance, delocalization, training and education, production technique, cluster, and business collaboration	Governmental supports on environmental practices and laws, sustainable materials used by suppliers, lower gas emissions from clean electricity source and filtration technology, environmental-friendly mode of transportation, local initiatives and demand on sustainable products [1]	Employment, economic growth, industrial retention, governmental support on chemical regulations, product safety, social benefits and compliances, and recycling regulations and infrastructure, local initiatives and demand on sustainable products[1], preservation of local culture and tacit knowledge
Supplier specific advantage	Size of suppliers, vertical suppliers, capacity flexibility, manufacturing capabilities on customization, high-value addition, and craftsmanship, ability to manufacture products to meet specifications and have quality consistency, product innovation from chemical regulations, ability to develop sample quickly, production knowledge and machinery, ability to utilize local materials	Ability to transform local wastes and by-products into materials, ability to produce materials and products without hazardous substances, lower dangerous wastes by good filtration technology at factories	Ability to produce materials and products without hazardous substances, good social compliances at factories such as working conditions and living wage payment.
Firm specific context	High-selling price of products, product types (cost structure of products between labor and materials inputs), ability to find and develop relationship with new suppliers, long-term relationship and good collaboration with suppliers or agents, ability to have production offices and local employees, having good communication technique and technology, ability to differentiate products by design and marketing, product variety,		Having certificates, concern on high living cost and seamstress wage

Remarks: [1]by sustainable product and consumption including slow fashion and circular economy concepts.

Table 4.2 reveals that how decisions on locating manufacturing in certain countries can simultaneously gain TBL benefits and get influenced by various factors relating to the benefits. These are shown in the interview and simulation findings that manufacturing location decisions are influenced by firm's strategies on product types, market positioning, and governance levels for controlling production quality, lead times, and environmental and social compliances as well as firm's resources on human and technology and look for and communicate with suppliers. The governance strategies such as visiting factories by managers from headquarters as well as relying on local agents in the manufacturing regions, audits, and certificates also depend on firm's resources. Governmental supports, trade policies, and environmental and social regulations and laws also influence the manufacturing location decisions. As a result, I propose a diagram showing summary on different manufacturing decisions and location configurations and how they get influenced by TBL factors and business contexts in Figure 4.1. TBL factors for manufacturing decisions are from common benefits between proximity and distant manufacturing. Business contexts are influenced by firm's strategies, resources, and capabilities as well as external environments and stakeholders.

4.3 Answers to research question 2 of the thesis

The previously-mentioned answers to RQ 1 show what influence different manufacturing decisions and location configurations in which TBL. This helps answer RQ 2: How can a focal firm objectively choose manufacturing locations of each supply stage for enhancing sustainable multi-tier supply chain of a product? The proposed model in Study 3 directly helps answer RQ 2 by incorporating TBL factors into objective measures, which are cost and CO2e, for multi-tier supply location decisions. Using the logic models technique during formulating the propose model help me realize factors and their pathways to each TBL sustainability which is the targeted outcome as shown in Figure 4.2. Figure 4.2 illustrates how each factor from manufacturing, logistics, and sustainability assurance activities is linked to cost and/or CO2e measurement criteria and influence business, environmental, and social/socio-economic sustainability either directly or indirectly through cost and CO2e.

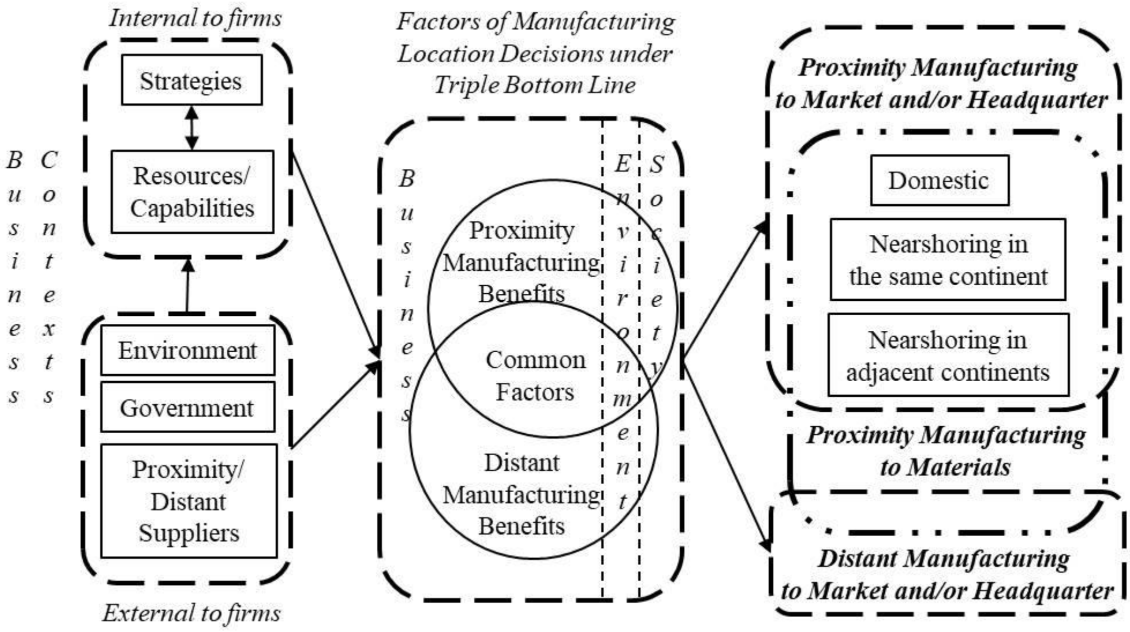

Figure 4.1 Summary on how different manufacturing decisions and location configurations get influenced by triple bottom line factors and business contexts.

Figure 4.2 shows how a focal firm, which is the primary actor of the model analysis, is connected to each factor, cost and CO2e measurement criteria, and TBL sustainability implying possibilities for the firms to influence TBL sustainability through different activities.

The model application in designing a new viscose t-shirt supply chain demonstrates that the model can help users to be objectively design where to source materials and produce final products for each market and all markets. According to the application objective, the findings show that nearshoring manufacturing to Germany in Africa with Austrian and American fibers are optimized cost and CO2e supply chains for all markets with warehouses in Germany, US, and China. Sensitivity and scenario analyses show not only robust outcomes but also important risk factors to be concerned.

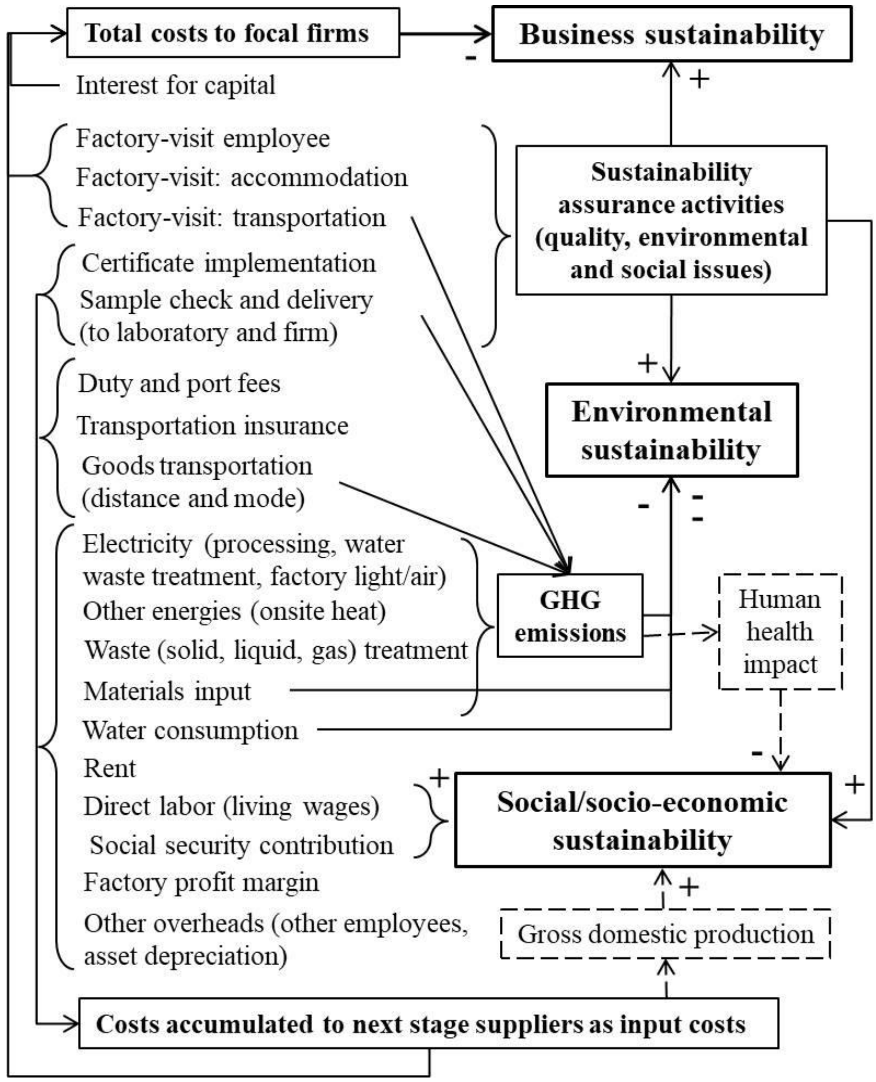

Figure 4.2 Relationships among suggested factors from manufacturing, logistics, and sustainability assurance activities, cost and GHG emission measurement criteria, and their impacts on sustainability dimensions (adapted from submitted paper)

Remarks: Positive and negative signs are impacts to business, environmental, and social/socio-economic sustainability; Dash boxes and lines show possible future research for creating the links among the three sustainability dimensions.

4.3.1 Potentials of the Proposed Model

The proposed model has potentials to support TBL sustainability because users can realize positive and negative impacts from supply chain activities on each TBL as shown in Figure 4.2. The users of this proposed model have to know their suppliers of suppliers; therefore, the model can help enhance supply chain visibility to the users. As shown in the model scheme in Figure 3.7, the proposed model shows high flexibility to meet users' preferences and constraints on manufacturing location decisions. Firstly, the proposed model supports multi-tier supply location decisions with the applications of both designing a new product supply chain and evaluating existing supply chains including comparing existing suppliers. Secondly, users can find and compare either total absolute costs/CO2e of different supply chain alternatives or total relative (differential) costs/CO2e among the alternatives by excluding costs/CO2e which is equal to every alternative such as design, marketing, warehousing, and selling activities performed by firms. Thirdly, the proposed model allows users to find common alternatives of supply locations among different markets in order to have one manufacturing supply chain for one product. If the manufacturing quantities are big enough to split productions for each market, users can also use the proposed model to find the best available alternative(s) of supply locations for each market according to users' cost/CO2e requirements and constraints. All of the three flexibilities differentiate this proposed model from existing models on manufacturing location decisions besides incorporated TBL factors and sustainability assurance activities for cost and CO2e calculation.

The three computational scopes in this proposed model allow users with different business models and operations to use the model effectively. Moreover, the model is based on research from different industries in terms of measurement criteria and their calculation. Therefore, it is highly likely that the current model with the suggested factors and activities for cost and CO2e is applicable to most industries. These enhance pragmatic validity and practical relevance by producing outcomes which are generic designs for other applications beyond a specific domain (Oliva, 2019). Additionally, this proposed model allows users to consider supply chains with high resistance to both local and global disruptive risks for long-term planning.

4.4 Theoretical Contributions, Research Limitations, and Future Research Directions

This thesis makes contributions to location theories, manufacturing location decisions, and sustainable multi-tier supply chain management through findings from multiple methods and from reviewing knowledge on international business, competitive advantage, and foreign direct investment.

The SLR induces the four inductive subgroups for the business sustainability that can be the basis for future research to categorize business factors, to analyze business and suppliers performances, and to formulate competitive advantage of the four subgroups. Moreover, this thesis shows unrevealed benefits and factors of proximity and distant manufacturing location decisions by the semi-structure interviews aside from what existing studies have usually mentioned. The interview findings show contrasting points to existing studies by revealing that complex and high-fashion garments are manufactured in distant locations rather than in proximity locations mentioned by some existing studies because of the distant suppliers' specialization and technology as well as relative low costs. The cost structure between materials price and operation minutes is another discovered factor from the interview. All mentioned findings benefit not only manufacturing decision literature including local, nearshoring, offshoring, and reshoring manufacturing but also sustainable supply chain design and management by knowing which factors should be considered for future research. The findings from SLRs and the proposed model application contribute to the location theory by adding locational factors to Weber (1929)'s locational and agglomerative factors (as shown in Table 1.1). The thesis results also present the importance and benefits of proximity manufacturing to headquarters besides proximity manufacturing to markets and material sources mentioned by Weber (1929).

This thesis reveals that TBL benefits derived from different kinds of proximity among supply chain stakeholders and from different country-, supplier-, and firm- specific advantages can be related and unique as shown in Table 4.1 and Table 4.2. Therefore, when researchers analyze and present positive and negative factors (benefits, benefits, and barriers) of manufacturing location decisions, researchers have to ensure on sources of the benefits whether the benefits are from spatial proximity to markets or else as well as from country-, supplier-, or firm-specific advantages. The manufacturing location decisions include local and domestic manufacturing, reshoring, nearshoring, and offshoring. Additionally, as there is no clear boundary and definition for location manufacturing, this thesis offers the view of local manufacturing as proximity manufacturing to market, to headquarter (home country), and to supplier (materials). This helps future research to be precise on their study context and scope.

This thesis reveals common proximity-manufacturing benefits among different markets and common benefits between proximity and distant manufacturing as shown in Table 4.1 and Table 4.2 in discussion. It can be seen that manufacturing location decisions of both proximity and distant manufacturing involve the Porter's (1990) diamond framework and have the similarity to the Rugman et al. (2012)'s double diamond framework for the regional and global competitiveness of multinational firms to expand their businesses and sales. This thesis presents cross knowledge between supply chain management and business strategies or economics. The thesis also points out the fact that focal firms make manufacturing location decisions for both in-house and outsourcing manufacturing in the same way as business expansion and investment decisions in order to acquire business competitiveness from country and supplier specific advantages as shown in Table 4.2. As a result, this thesis offers a view for future research and practices to use the Porter's diamond framework for manufacturing location decisions and aligning all supply chain functions from production to sales in order to create firm's competitive advantages.

The differentiated results of this thesis and both diamond frameworks (M. Porter, 1990; Rugman et al., 2012) are about firm's strategies. Besides national contexts and circumstances as mentioned by M. Porter (1990), firms' strategies, goals, and structures depend on firms' resources. According to Study 2, firms from the same industry and country have different strategies, goals, and structures. The reason could be that Swedish firms hardly gain any governmental support as shown in the SLRs that governmental supports under the business dimension in Europe is much lower than in Asia and US. Therefore, the Swedish firms rely on themselves and seek advantages from other nations as shown in Table 4.2 in order to create firm's competitiveness to achieve business sustainability. Conducting similar research to Study 2 in other countries and continents with high and low governmental support will help confirm the reason. Furthermore, based on Figure 4.1, future research can further explore the intra- and inter-correlations among business contexts, factors of proximity and distant manufacturing, and manufacturing location decisions and location configurations.

The thesis findings show the benefits of vertical suppliers and agglomeration for manufacturing location decisions of both proximity and distant manufacturing and for low cost and CO2e supply chain design. The spatial proximity gives benefits on reduced coordination and transactional costs as well as possibilities for knowledge spillovers concurrent to the John H. Dunning (2009) study on foreign direct investment locations. Nevertheless, this thesis additionally shows the benefits of agglomeration in reducing lead times and firm costs of visiting factories for sustainability assurance.

The proposed model from this thesis contribute to sustainable supply chain management (SSCM) studies whose current modeling overlooks retailers as a primary actor of analysis and inter-organizational perspectives relating different stakeholders and multi-tier suppliers within supply chain networks. Furthermore, important factors which are resulted from the model application can be further used in future supply chain and SSCM studies. The proposed model in this thesis also advances knowledge on cost and CO2e calculation in order to avoid hidden cost and CO2e in supply chains from different activities and locations because the proposed model includes sustainability assurance activities and TBL factors which have not been considered in other cost and CO2e modelling for manufacturing location decisions. As mentioned in section 4.2.1, the model potentials have high flexibilities for users on different objectives, cost and CO2e computation, and supply chain selection for different markets. This implies that users have to know their preferences and constraints for using the model effectively. If users choose objectives to gain optimized cost and CO2e supply chains, the model will give sets of the optimized supply chains and users have to select the final supply chain based on their cost and CO2e preferences and constraints.

Future research possibly adds other environmental measurement criteria and socio-economic measurement criteria such as human health impacts and gross domestic industries for updating the model. However, three and more measurement criteria will require suggested processes to users on gauging different measurement criteria to choose the supply chains which meet their preferences on TBL. Additionally, the current model is possibly improved by system dynamic modelling and automated program.

As this model has been tested in only the textile and clothing industry and with a small produced-unit batch, future research may apply this model in other industries with a bigger-size batch. Though, the model application has shown different number of manufacturing batches referring to small to big total number of produced units, future research on a bigger-size batch may see different effects of logistics costs on supply chain cost and CO2e. In order to enhance results of low cost and CO2e supply chains for the US market, the model application in viscose t-shirt supply chains can be improved by adding manufacturing locations in proximity to US as Adikorley et al. (2017) showed that nearshoring in South America provided the best lead time for the US market followed by Asia and Africa.

4.5 Practical and Social Implications and Contributions

4.5.1 Industrial Practitioners

The findings of this thesis shows that for products that require regular factory visits, firms can choose either proximity manufacturing to their headquarters or having local employees at manufacturing locations in order to visit factories easily for shortening total lead time from face-to-face discussions of product specifications and prices leading to quick finalization to start production faster as well as for reducing costs and CO2e in the product supply chain as shown in the proposed model application. Specifically to textile and clothing industries, shorten lead time can be achieved by advanced fabric preparation strategies allowing companies to be responsive to demand especially with proximity manufacturing to markets. Designing and selling basic, carry-over-style, or never-out-of-stock garments help reduce risks from advanced fabric preparation due to continuous demand and production as well as relative small number of items to be stocked. Using real garments as a ground to make suppliers properly understand what headquarter designers want lead to fast prototype development which helps shorten total lead times. Having in-house prototype production at the headquarter also helps designers to finish a designed prototype quickly, accurately, and feasibly for production running as well as companies to be able to offer product customization and after-sale services to customers. All of these strategies give benefits to all TBL sustainability because short total lead times allow firms to have accurate forecasting on the amount and style of produced garments desired by uncertain markets leading to few leftovers which imply less wastes on landfills and resources consumption to produce unused units.

Regarding manufacturing location decisions, the interviews show that all managers still overlook emissions from electricity/energy generation and manufacturing technology which mainly contribute to carbon emissions of a supply chain. Therefore, managers should choose factories using filtration technology and locations with renewable energy sources when making manufacturing location decisions or designing a product supply chain in order to enhance environmental sustainability.

Industrial practitioners can use the proposed model to design and select multi-tier supply locations in order to enhance sustainability in their product supply chains. The model aids not only financial planning but also carbon emission planning and ensure good social compliances at factories for current situations of increasing environmental regulations and attentions on social compliances. When decreasing and increasing each manufacturing cost/CO2e of each location, some new lowest cost/CO2e supply chains are revealed. Therefore, managers can consider these supply chains with high resistance to risk factors for long-term planning.

4.5.2 Policy Makers

The SLR findings highlight role of governments worldwide with the potentials to support TBL sustainability through proximity manufacturing. Therefore, policy makers can support proximity manufacturing and local business through efficient business infrastructures in terms of workers' training and education for skilled-worker availability, efficient low cost and carbon emission logistics, business alliances and collaboration platforms, industrial clustering and resource sharing, duty fees, and research and innovation. Moreover, the interviewed findings show that European chemical laws for non-contaminated products enable proximity manufacturing to the European market. This demonstrates the potentials of policy makers to support both environmental and social sustainability by preventing harmful chemicals in manufacturing processes and final products for the safety of environments, workers, and consumers. Furthermore, policy makers may support material suppliers to be competitive and vertical manufacturing in order to draw investment to their locations as the interview findings show that proximity between fabric and garment manufacturers is an important factor for manufacturing location decisions.

Policy makers can use the proposed model to strategically create business infrastructures and laws in order to enhance competitiveness of local product supply chains by making comparison with other competitive supply locations. By changing each cost in each location, policy makers can realize which factors to be intervened and supported in order to make their countries to be manufacturing locations through cost competitiveness. They can also realize some costs such as water and electricity cannot make their locations to be competitive to the others in terms of low cost. Increasing duty fees do not make some local supply chains become competitive as shown by the model application.

As I encounter the difficulty in collecting data among the cities and countries, international and local authorities may collaborate to create a platform for data relating to manufacturing and logistics so that business and researchers can use to design sustainable low cost and CO2e supply chains. They can use the proposed model to check whether data required in the model are publicly available to businesses and researchers in order to support implementations and research on sustainable supply chains.

Besides contributing to research, this thesis encourages industrial practitioners and policy makers to consider costs and CO2e from all supply chain activities performed by any actors such as manufacturers, energy suppliers, brand retailers, consumers in order to avoid hidden cost and CO2e in some overlooked activities such as sustainability assurance activities and electricity production. The model application demonstrates that majority of CO2e are from manufacturing activities especially materials manufacturing which can be in any parts of the world outside the headquarters' location. Therefore, emission trading schemes may include carbon emissions from all product-related activities as shown in the model rather than from only activities performed by individual businesses located in the area boundary of the emission trading schemes.

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Appendices

Appendix A: Study 1 Systematic Literature Review Additional Results

According to the systematic literature review of the 45 primary studies published during 1997 to 2016, Figure A.1 shows how each primary study involves in each TBL and business subgroups while Figure A.2 shows frequently-mentioned benefits under each TBL and the four business subgroups across time and studied market. On the y-axis of Figure A.2, the total number of articles studied each market in blankets is more than the shown primary studies with the published years because some studies do not mention the highly-mentioned benefits.

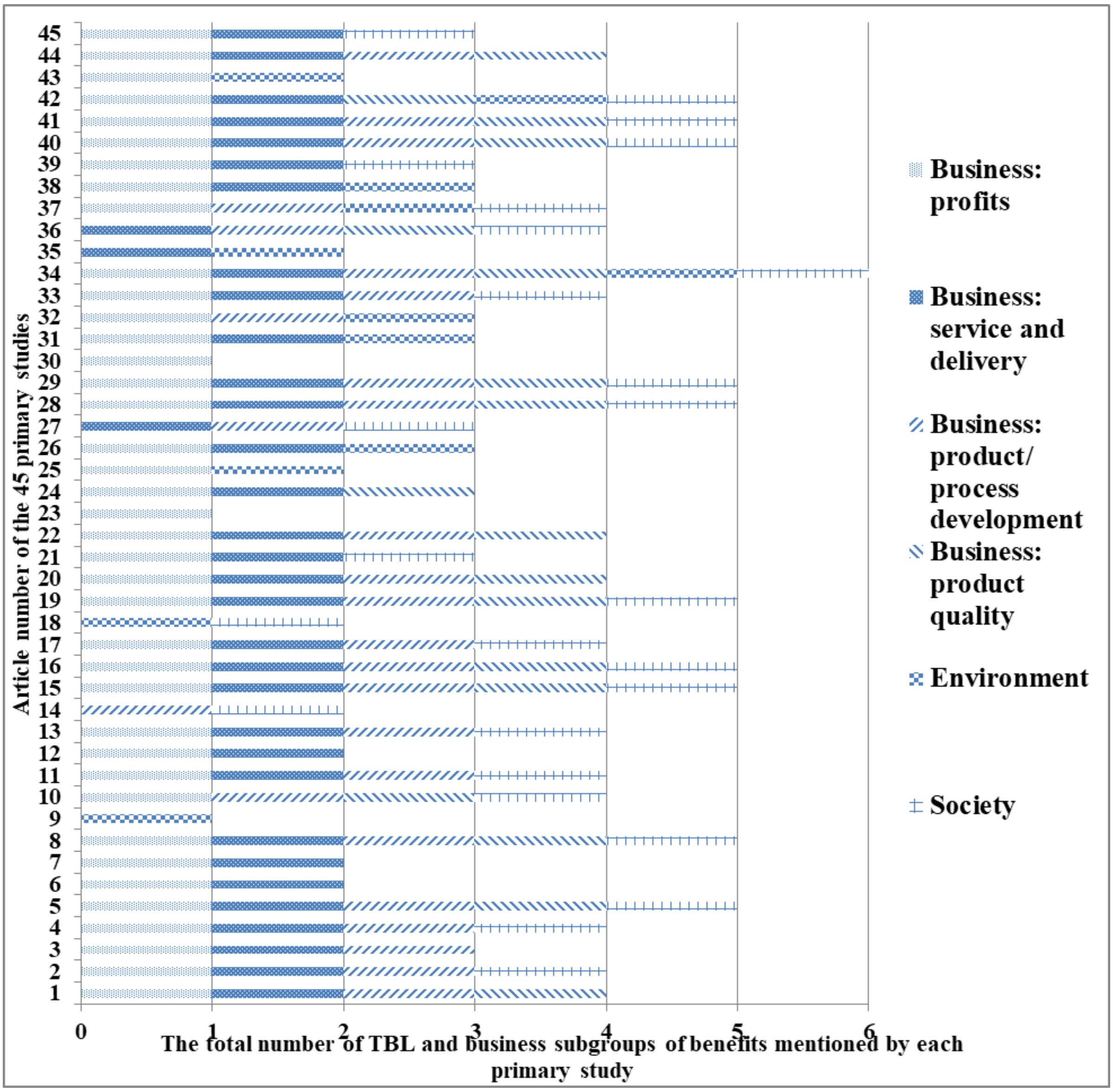

Figure A.1 TBL dimensions and business subgroups of factors mentioned by each primary study.

Remark: The article numbers refer to Table 2.2.

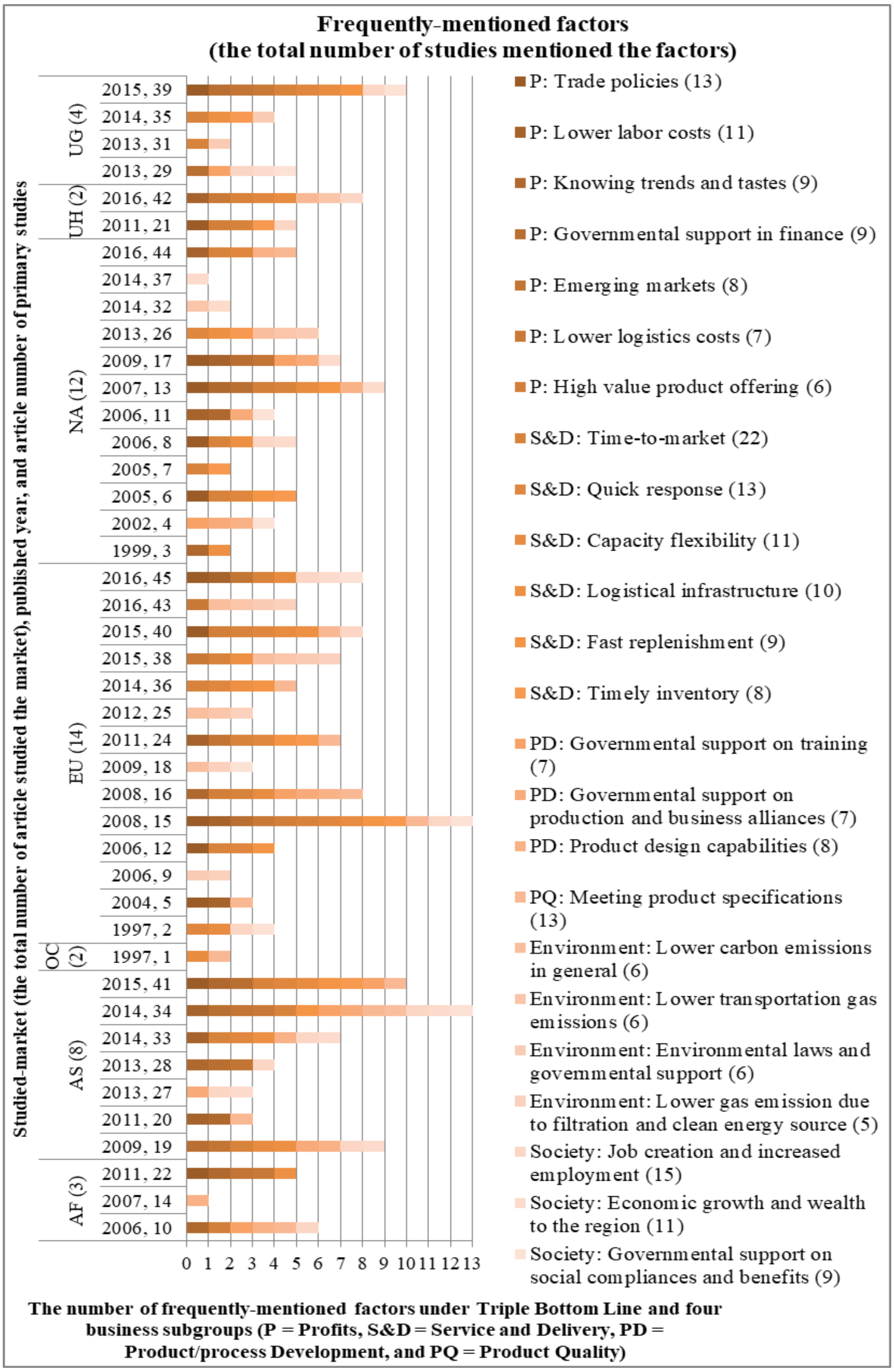

Figure A.2 Frequently-mentioned benefits relating to Triple Bottom Line and four business subgroups in chronological lists under each studied market.

Remarks: AF = Africa, AS = Asia, EU = Europe, NA = North America, OC = Oceania, UH = Unspecified High cost locations, UG = Unspecified Global locations, P = Profits, S&D = Service and delivery, PD = Product and process development and innovation, and PQ = Product quality; and the article numbers refer to Table 2.2.

Appendix B: Study 3.2 Manufacturing Data

In the below tables, the data with grey highlight indicate users' inputs while the others are resulted from formula calculation.

Fiber Manufacturing Stage

Table B.1 Cradle-to-factory gate energy use for man-made cellulose fibers manufacturing.

Manufacturing locations	Austria	China (Nanjing)	Indonesia	Great Britain	USA	Thailand
Non-renewable enery use, MJ/kg	19	61	61	61	61	61
Renewable enery use, MJ/kg	51	45	45	45	45	45
NREU with coefficients, MJ	10260	32942	32942	32942	32942	32942
REU with coefficients, MJ	27541	24301	24301	24301	24301	24301

Remark: Data with gray highlights are from L. Shen and Patel (2010).

Fabric and Garment Manufacturing Stages

Table B.2 Inputs and outputs of each process in fabric and garment manufacturing.

Supply stage	Parameter	Unit	Calculated input data	Referred data (Angelstam et al., 2016)	Remarks
Thread spinning process	Input: viscose fiber	kg	540.02	1.22	
	Electricity	kWh	2.09	0.0047222	for electricity cost and CO2e
	Output: viscose thread	kg	442.64	1	
Knitting and dyeing process	Input: viscose thread	kg	442.64	10,886,216.88	
	Water	m3	73.19	1,800,000	for water cost, electricity CO2e in water waste treatment
	Electricity	kWh	6.41	157,600	for electricity cost and CO2e
	Heat	kWh	541.34	13,313,521.07	for wood cost and CO2e
	Output: viscose knit	kg	442.64	10,886,220	
	Solid waste	kg	97.38		for landfill CO2e
Cutting and sewing process	Input: viscose knit	kg	442.64	1,414	
	Water	m3	0.16	0.52	for water cost and electricity CO2e in water waste treatment
	Electricity	kWh	624.52	1,995	for electricity cost, CO2e
	Output: viscose t-shirt	kg	360.00	1,150	
	Solid waste	kg	82.64		for landfill CO2e

Table B.3 Wastewater treatment electricity in fabric and garment manufacturing.

Supply stage	Parameter	Unit	Input data	Remarks
Referred data (H. Yin et al., 2019)	%Reclaimed water in primary water reuse system (WRS)	%	0.67	
	%Reclaimed water in secondary WRS	%	0.198	
	Used electricity rate in primary WRS	kWh/m3	2.81	
	Used electricity rate in secondary WRS	kWh/m3	3.8	
Knitting and dyeing process	Electricity used in primary WRS	kWh	137.88	for electricity cost and CO2e
	Electricity used in secondary WRS	kWh	55.07	for electricity cost and CO2e
Cutting and sewing process	Electricity used in primary WRS	kWh	0.31	for electricity cost and CO2e
	Electricity used in secondary WRS	kWh	0.12	for electricity cost and CO2e

Table B.4 Overheads electricity consumption in fabric and garment manufacturing.

Supply stage	Parameter	Unit	Input data	Remarks
Referred data*	Monthly energy for air conditioning	kWh/month	234000	*https://www.textileschool.com/245/energy-consumption-for-spinning-machines-and-compressed-air/
	Monthly energy for illuminating	kWh/month	43200	
	For total yarn production	kg/month	401580	
Fabric factory	Required electricity for air conditioning	kWh	257.93	for electricity cost and CO2e
	Required electricity for illumination	kWh	47.62	for electricity cost and CO2e
Garment factory	Required electricity for air conditioning	kWh	199.89	for electricity cost and CO2e
	Required electricity for illumination	kWh	36.903	for electricity cost and CO2e

Table B.5 Machine and direct labor in fabric and garment manufacturing.

Supply stage	Parameter	Unit	Input data	Remarks
Thread spinning process	Machine capacity	kg/hr	51.03	www.alibaba.com/product-detail/
	Required machine operation time	hr	8.67	
	Direct labor required	person	2	
	Required labor operation time	hr	17.35	for labor cost (medium skill wage)
Yarn dyeing process	Package dyeing machine capacity[1]	kg/hr	42.50	[1]Amin (2014)
	Required machine operation time	hr	10.42	
	Direct labor required	person	2	
	Required labor operation time	hr	20.83	for labor cost (medium skill wage)
Fabric circular knitting	Machine capacity, produced fabrics[1]	kg/hr	9.54	
	Number of machine	machine	2	
	Required machine operation time	hr	23.20	for overhead costs
	Direct labor required	person	1	
	Required labor operation time	hr	23.20	for labor cost (medium skill wage)
	Total number of operators in factory	person	5	for certificate implementation cost
	Fabric factory productivity	%	100	
	Fabric factory working time per batch	hr	23.20	for overhead cost allocation
Cutting process	Cutting machine capacity, LECTRA1	yard/minute	3.26	Phakphonhamin and Chudokmai (2018)
	Required fabric	yard	1792.89	
	Required machine operation time	hr	9.16	
	Direct labor required	person	1	for labor cost (medium skill wage)
	Required labor operation time	hr	9.16	for labor cost (medium skill wage)
Sewing process	Operation minutes for a garment[2]	minutes	6.48	[2]Rahman, Roy, Karim, and Biswas (2014)
	Required machine operation time	hr	194.40	
	Total number of operators[2]	person	19	for labor cost (medium skill wage)
	Total number of helpers[2]	person	3	for labor cost (low skill wage)
	Required labor operation time	hr/person	10.23	for overhead costs, garment labor cost
	Total number of operators	person	20	for certificate implementation cost
	Total number of helpers	person	3	for certificate implementation cost
	Garment factory productivity	%	100	
	Garment factory working time per batch	hr	10.23	for overhead cost allocation

Table B.6 Rent and indirect labor in in fabric and garment manufacturing.

Supply stage	Parameter	Unit	Input data	Remarks
Fabric factory including spinning and dyeing	Fabric factory size	m2	600	for rent cost
	Plant manager	person	1	for labor cost (highest high skill wage), certificate implementation cost
	Inspector, purchaser, sales, HR	person	4	for labor cost (use medium/average high skill wage), certificate implementation cost
	Cleaners	person	3	for labor cost (low skill wage), certificate implementation cost
	Other overheads	%	10	Depreciations and interest on capitals
	Profit margin	%	10	
	Total employees	person	13	
Garment factory	Garment factory size	m2	465	for rent cost
	Plant manager	person	1	for labor cost (highest high skill wage), certificate implementation cost
	Inspector, purchaser, sales, HR	person	4	for labor cost (average high skill wage), certificate implementation cost
	Cleaners	person	2	for labor cost (low skill wage), certificate implementation cost
	Other overheads	%	10	Depreciations and interest on capitals
	Profit margin	%	10	
	Total employees	person	30	

Table B.7 Manufacturing working-time conversion.

Parameter	Unit	Input data	Remarks
Factory working months/year	month	12	
Factory working days/month	day	26	for rent cost and solid waste cost, labor overhead
Number of hours per shift	hour	8	for rent cost and solid waste cost, labor overhead
Number of shifts per day	shift	2	for rent cost and solid waste cost

Table B.8 Biomass energy calorific value.

Parameter	Unit	Input data	Remarks
Calorific values of fuel wood	MJ/kg equal TJ/Gg	15.60	https://ghgprotocol.org/calculation-tools, Excel Sheet emission factor tool March 2017 (access 2019/12/25)

Appendix C: Study 3.2 Cost Data

In the below tables, the data with grey highlight indicate users' inputs while the others are resulted from formula calculation.

Table C.1 Cost rates of fiber, electricity, woodchip, water, solid waste, rent, interest, and used cloth.

Manufacturing locations	Fiber rate, €/kg	Industrial electricity rate, €/kWh	Woodchip rate, €/kg	Industrial water rate, €/m3	Solid waste fee[23], €/year	Rent rate, euro/m2/ month	Interest rate, %	Used cloth price
Austria	2.29[1]	0.10[2]	0.06[10]	2.82[13]	282.45	4.62[24]		
China (Nanjing)	1.69[1]	0.10[3]	0.06[10]	0.98[14]	211.39	3.58[25]		1.06[39]
Indonesia	1.77[1]	0.07[4]	0.07[10]	0.61[15]	155.62	3.06[24]		
Great Britain	2.43[1]	0.13[2]	0.02[10]	4.60[13]	282.45	3.72[26]		
USA	1.22[1]	0.06[5]	0.07[10]	0.90[13]	282.45	5.05[27]		2.75[39]
Thailand	2.11[1]	0.07[4]	0.05[10]	0.68[16]	211.39	2.70[28]		
Germany		0.15[2]	0.09[10]	4.13[17]	282.45	3.73[29]	1.93[38]	1.00[39]
Italy		0.14[2]	0.10[10]	0.74[13]	282.45	4.75[30]		
Poland		0.09[2]	0.07[10]	2.44[13]	282.45	3.18[31]		
Lithuania		0.08[2]	0.06[10]	2.98[17]	282.45	2.65[32]		
Tunisia		0.05[6]	0.13[10]	0.54[18]	155.62	0.98[33]		
Egypt		0.05[7]	0.07[11]	0.30[19]	155.62	2.78[34]		
Turkey		0.06[2]	0.07[10]	1.71[20]	211.39	2.42[35]		
China (Shanghai)		0.12[3]	0.06[10]	0.98[14]	211.39	5.96[25]		
Bangladesh		0.09[8]	0.10[10]	0.37[21]	155.62	0.78[36]		
India		0.06[9]	0.05[12]	0.04[22]	155.62	1.59[37]		

Remarks: [1]www.seair.co.in/import-data-hs-code-5504.aspx,
[2]https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Electricity_prices,_First_semester_of_2016-2018_(EUR_per_kWh).png,
[3]www.ceicdata.com/en/china/electricity-price?page=3,
[4]www.en.netralnews.com/news/business/read/23765/energy.ministry.electricity.tariffs.in.indonesia.most.stable.in.southeast.asia,
[5]www.rockymountainpower.net/about/rar/ipc.html,
[6]https://energypedia.info/wiki/Tunisia_Energy_Situation,
[7]https://madamasr.com/en/2018/06/13/news/u/government-raises-electricity-tariffs-for-industrial-producers-by-up-to-43/,
[8]www.thedailystar.net/frontpage/power-tariff-rise-dec-1495777,
[9]www.reuters.com/article/india-pollution-power/india-power-tariffs-could-rise-62-93-paise-kwh-power-minister-idUSL4N1OX1PP,
[10]www.alibaba.com/product-detail,

[11]http://pellets-wood.com/wood-pellets-for-sale-from-egypt-o14715.html,
[12]www.indiamart.com/proddetail/wooden-chips-20163248173.html,
[13]https://read.oecd-ilibrary.org/environment/environment-at-a-glance-2015_9789264235199-en#page39,
[14]https://piie.com/blogs/china-economic-watch/economics-h2o-water-price-reforms-china,
[15]http://open_jicareport.jica.go.jp/pdf/12028130.pdf,
[16]www.boi.go.th/newboi/upload/content/Cost%20of%20doing%202018-date_7%20Mar%202018_5aa7c1f8ae9b4.pdf,
[17]https://iwa-network.org/publications/international-statistics-for-water-services-2012/,
[18]www.investintunisia.tn,
[19]https://tariffs.ib-net.org/ViewTariff?tariffId=2254&countryId=141,
[20]http://rotacapital.com/invest%20in%20turkey%20guide.pdf,
[21]www.thedailystar.net/frontpage/utility-tariffs-water-gas-and-electricity-price-increase-1574113,
[22]https://timesofindia.indiatimes.com/city/mumbai/maharashtra-govt-increases-water-tariff-for-industries-using-it-as-raw-material/articleshow/62573525.cms,
[23]Three groups of solid waste management by country incomes, Table 5.5 in https://openknowledge.worldbank.org/handle/10986/30317,
[24]www.realestate.com.au/international/at/rent/industrial-warehouse/p4/,
[25]https://www.dbs.com/aics/pdfController.page,
[26]https://realla.co/rent/industrial/Grimsby,
[27]https://www.loopnet.com,
[28]www.ddproperty.com,
[29]https://en.arkadia.com/for-rent/commercial/germany-g276,
[30]www.engelvoelkers.com/en-it/properties/,
[31]www.poland-industrial.com,
[32]https://investlithuania.com/investor-guide/running-your-business/,
[33]www.homeintunisia.com/en/rentals/industriel-permises,
[34]www.healyconsultants.com/egypt-company-registration/free-zones,
[35]http://duzeneremlak.com,
[36]https://bdnews24.com/classifieds/commercial-property/factory-rent-in-bangladesh.html,
[37]www.realestateindia.com/property-detail/factory-industrial-building-for-rent-in-bhatar-road-surat-5000-sq-ft-768232.htm,
[38]https://tradingeconomics.com/germany/bank-lending-rate, Oct 2019 rate, access 2019/12/26,
[39]www.alibaba.com/product-detail.

Table C.2 Helper/cleaner wage.

€/month Locations	Minimum wage	Living wage for typical family Lowest	Living wage for typical family Highest	Living wage for typical family Average	Low-skilled job wage Lowest	Low-skilled job wage Highest	Low-skilled job wage Average	**Helper/ cleaner wage**
Austria	-	1,470.00	1,880.00	1,675.00	1,536.00	1,844.00	**1,690.00**	**1,690.00**
China (Nanjing)	162.00	453.43	453.43	**453.43**	N/A	N/A	N/A	**453.43**
Indonesia	101.00	145.00	184.00	164.50	154.00	215.00	**184.50**	**184.50**
Great Britain	1,517.00	1,091.00	1,564.00	1,327.50	1,344.00	1,566.00	**1,455.00**	**1,455.00**
USA	1,135.00	1,444.00	2,094.00	**1,769.00**	1,221.00	1,812.00	1,516.50	**1,769.00**
Thailand[1]	**290.40**	N/A	N/A	N/A	N/A	N/A	N/A	**290.40**
Germany	1,553.00	1,520.00	2,000.00	1,760.00	1,606.00	1,997.00	**1,801.50**	**1,801.50**
Italy	-	1,120.00	1,510.00	**1,315.00**	927.00	1,205.00	1,066.00	**1,315.00**
Poland	525.00	452.00	770.00	**611.00**	517.00	608.00	562.50	**611.00**
Lithuania	555.00	695.00	960.00	**827.50**	401.00	489.00	445.00	**827.50**
Tunisia[1]	**221.81**	N/A	N/A	N/A	N/A	N/A	N/A	**221.81**
Egypt	67.00	133.00	193.00	**163.00**	98.00	132.00	115.00	**163.00**
Turkey	320.00	405.00	584.00	**494.50**	189.00	218.00	203.50	**494.50**
China (Shanghai)	162.00	530.67	530.67	**530.67**	N/A	N/A	N/A	**530.67**
Bangladesh	16.00	144.38	174.36	**159.37**	48.00	65.00	56.50	**159.37**
India	52.00	195.00	286.00	**240.50**	119.00	166.00	142.50	**240.50**

Remarks: Numbers in bold refer to where the helper/cleaner wages come from; [1]www.minimum-wage.org; wages of the others are from https://wageindicator.org/salary/wages-in-context; and all were accessed at 20/12/2019.

Table C.3 Operator wage.

€/month	Medium-skilled job wage			
Locations	Lowest	Highest	Average	**Operator wage**
Austria	2,125.00	2,639.00	2382.00	2,382.00
China (Nanjing) [1]	205.29	481.15	343.22	**453.43**
Indonesia	196.00	264.00	230.00	230.00
Great Britain	1,718.00	2,141.00	1929.50	1,929.50
USA	1,623.00	2,387.00	2005.00	2,005.00
Thailand[2]	382.79	395.87	389.33	389.33
Germany	2,167.00	2,826.00	2496.50	2,496.50
Italy	1,342.00	1,678.00	1510.00	1,510.00
Poland	665.00	836.00	750.50	750.50
Lithuania	513.00	655.00	584.00	**827.50**
Tunisia[3]	222.04	265.93	243.98	243.98
Egypt	128.00	187.00	157.50	**163.00**
Turkey	206.00	263.00	234.50	**494.50**
China (Shanghai) [1]	205.29	481.15	343.22	**530.67**
Bangladesh	50.00	76.00	63.00	**159.37**
India	180.00	282.00	231.00	**240.50**

Remarks: Number in bolds refer to living wages because medium-skilled job wages of the countries are less than living wage; [1]https://wageindicator.org/documents/publicationslist/publications-2016/wages-in-context-in-the-garment-industry-in-asia-the-case-of-china; [2]https://tradingeconomics.com/thailand/wages-in-manufacturing; [3]www.numbeo.com/cost-of-living/in/Monastir-Tunisia; wages of the others are from https://wageindicator.org/salary/wages-in-context; and all were accessed at 20/12/2019.

Table C.4 Wages of plant managers and other administrative employees and employer social security contribution rate.

€/month Locations	High-skilled job wage[1] Plant Manager position	 Other position	Average wage of manager and other positions	**Manager wage**	**Other administrative employee wage**	Social security contribution rate[2], %
Austria	6,037.17	1,293.75	**3,665.46**	6,037.17	**3,665.46**	21.38
China (Nanjing)	3,062.24	518.92	**1,790.58**	3,062.24	**1,790.58**	32.00
Indonesia	2,349.63	1,870.39	2,110.01	2,349.63	1,870.39	9.74
Great Britain	5,747.87	5,691.83	5,719.85	5,747.87	5,691.83	13.80
USA	7,265.47	6,783.39	7,024.43	7,265.47	6,783.39	7.65
Thailand	3,469.81	1,879.24	2,674.52	3,469.81	1,879.24	5.00
Germany	7,203.75	6,621.42	6,912.58	7,203.75	6,621.42	19.83
Italy	7,004.17	6,234.33	6,619.25	7,004.17	6,234.33	30.00
Poland	3,305.20	3,305.20	3,305.20	3,305.20	3,305.20	21.00
Lithuania	8,142.08	892.92	**4,517.50**	8,142.08	**4,517.50**	1.77
Tunisia	1,859.46	142.74	**1,001.10**	1,859.46	**1,001.10**	16.57
Egypt	1,980.44	809.73	1,395.09	1,980.44	809.73	26.00
Turkey	2,051.43	2,005.68	2,028.55	2,051.43	2,005.68	22.50
China (Shanghai)	4,818.76	4,195.43	4,507.09	4,818.76	4,195.43	32.00
Bangladesh	1,777.77	85.75	**931.76**	1,777.77	**931.76**	0.00
India	1,814.82	1,471.84	1,643.33	1,814.82	1,471.84	12.00

Remarks: Numbers in bold for wages of other administrative employees are from average high-skilled wages because current wages show significant low salaries for the skills; [1]www.averagesalarysurvey.com with the selection of relevant careers to managers, human resource or human resource and marketing managers based on at least 20 observations in order to be concurrent to wageindicator.org criteria. If the number of observations for each career does not reach 20 observations, the lowest and highest salaries from earning percentages, which are more than 20%, are used; [2]https://home.kpmg/xx/en/home/services/tax/tax-tools-and-resources/tax-rates-online/social-security-employer-tax-rates-table.html.

Table C.5 Fabric testing cost with laboratory.

	£	Min, €	Max, €	Average, €	Reference
Fabric testing	45-60	52.72	70.29	61.50	https://www.cemarking-handmadetoys.co.uk/lab-testing/

Table C.6 Sample delivery cost and lead-time.

	Fabric XS,600g[1], €	Garment S,1kg[1], €	Lead-time, Europe[2], day	Lead-time, others[2], day
Sample delivery	5.70	6.20	2.00	7.50
Number of sample delivery	2	1		

Remarks: [1]www.deutschepost.de/de/b/briefe-ins-ausland/warenpost-international.html# by euro/pack with signature; and [2]www.logistics.dhl/fr-en/home/all-products-and-solutions/parcel-and-document-shipping.html.

Table C.7 Certificate cost including employee cost to learn and perform sustainable practices at a factory.

Maximum turnover, €	Annual Turnover	Certificate Fee[1] (£)	Auditing Fee[1] (£)	Total fees for certificates and audits for three years, €
117,146.00	Up to £100,000	995.00	450.00	1,692.76
292,865.00	£100,000 - £250,000	1,295.00	500.00	2,102.77
585,730.00	£250,000 - £500,000	1,495.00	550.00	2,395.64
1,171,460.00	£500,000 - £1 Million	1,795.00	600.00	2,805.65
1,757,190.00	£1 - 1.5 Million	1,995.00	650.00	3,098.51
2,342,920.00	£1.5 - 2 Million	2,295.00	700.00	3,508.52
3,514,380.00	£2 - 3 Million	2,795.00	750.00	4,152.83
	£3 - 5 Million	2,995.00	850.00	4,504.26

Remarks: [1]https://www.cqsltd.com/about-cqs/fees.aspx; certificate fee is valid for three years; time for manager and other employees to learn and perform sustainable practices for the certificate are 608 and 192 hours.

Table C.8 Costs and time of sustainability assurance activities performed by focal firms.

	Flight from Dusseldorf airport[1], €	Domestic travel costs[2], € (taxi or rental car)	Fuel costs for rental car[3], €	Total trip time, days	Hotel cost[4]	Number of car rental days	Number hotel night
Austria	299.62	153.78	20.00	3	144.00	3	2
China (Nanjing)	1,762.64	42.00		6	122.00	4	3
Indonesia	1,259.24	80.00		6	140.00	4	3
Great Britain	485.75	63.87	8.00	4	217.00	4	3
USA	1,650.65	221.27	38.00	6	139.00	4	3
Thailand	1,056.73	80.00		5	93.00	4	3
Germany	-	110.00	-	3	-	-	-
Italy	269.05	49.58	6.00	3	97.00	3	2
Poland	237.84	72.06	38.00	3	50.00	3	2
Lithuania	357.75	10.00		4	94.00	4	3
Tunisia	698.94	24.00		5	76.00	4	3
Egypt	576.45	24.00		5	44.00	4	3
Turkey	335.88	40.00		4	53.00	4	3
China (Shanghai)	904.78	50.00		6	167.00	4	3
Bangladesh	1,292.11	12.00		6	102.00	4	3
India	984.09	12.00		6	74.00	4	3

Remarks: [1]www.lufthansa.com, [2]www.rentalcars.com, [3]www.rome2rio.com, [4]www.booking.com with the selection of review score 8+, breakfast,hotel only, and all data were accessed on 16th July 2019.

Table C.9 Ship and truck transportation costs between 16 manufacturing locations.

From/to	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	To port
1	0	451	451	451	585	451	**0.06**	**0.05**	**0.07**	**0.11**	451	451	451	451	451	451	0.03
2	567	0	451	458	647	451	464	451	451	451	451	624	583	**0.01**	480	451	0.01
3	451	451	0	451	738	451	451	451	451	451	451	451	451	451	451	451	0.00
4	451	552	451	0	504	451	451	451	451	451	451	451	451	552	716	582	0.00
5	665	734	917	459	0	934	451	594	503	523	594	733	683	734	1246	1006	0.02
6	451	451	451	451	752	0	451	451	451	451	451	451	451	451	451	451	0.01
7	**0.06**	542	451	451	495	451	0	**0.07**	**0.08**	**0.12**	451	451	451	542	702	571	0.02
8	**0.05**	451	451	451	558	451	**0.07**	0	**0.11**	**0.16**	451	451	451	451	501	571	0.02
9	**0.07**	597	451	451	547	451	**0.08**	**0.11**	0	**0.05**	451	451	451	597	612	506	0.03
10	**0.11**	620	451	451	568	451	**0.12**	**0.16**	**0.05**	0	451	463	451	620	636	526	0.02
11	451	451	451	451	558	451	451	451	451	451	0	451	451	451	501	451	0.03
12	451	451	451	451	711	451	451	451	451	451	451	0	451	451	482	451	0.02
13	451	451	451	451	663	451	451	451	451	451	451	451	0	451	451	451	0.00
14	567	**0.01**	451	458	647	451	464	451	451	451	451	624	583	0	480	451	0.00
15	451	451	451	548	726	451	538	451	466	484	451	451	451	451	0	451	0.02
16	451	451	451	518	687	451	509	451	451	457	451	451	451	451	451	0	0.02
From port	0.03	0.01	0.00	0.00	0.02	0.01	0.02	0.01	0.03	0.02	0.03	0.02	0.00	0.00	0.01	0.02	

Remarks: Bold refer to truck cost (€/kg) and the rest is the less than container load price of ship transportation (€/ton); truck cost (€/kg) between port and factory are shown in the last row and column; 1-16 represent manufacturing locations in Austria, China(Nanjing), Indonesia, Great Britain, The United States, Thailand, Germany, Italy, Poland, Lithuania, Tunisia, Egypt, Turkey, China(Shanghai), Bangladesh, and India, respectively; and all data are from www.searates.com and www.worldfreightrates.com/freight accessed in April 2019.

Table C.10 Fiber import duty fees in percentage.

From/to	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	5	5	0	4.3	0	0	0	0	0	0	0	0	5	0	20
2	4	0	0	4	4.3	0	4	4	4	4	0	0	4	0	0	20
3	0	0	0	0	4.3	0	0	0	0	0	0	0	0	0	0	20
4	0	0	5	0	4.3	0	0	0	0	0	0	0	0	5	0	20
5	4	5	5	4	0	0	4	4	4	4	0	0	4	5	0	20
6	4	0	0	4	4.3	0	4	4	4	4	0	0	4	0	0	20

Remarks: 1-16 represent manufacturing locations in Austria, China(Nanjing), Indonesia, Great Britain, The United States, Thailand, Germany, Italy, Poland, Lithuania, Tunisia, Egypt, Turkey, China(Shanghai), Bangladesh, and India, respectively; and data are retrieved in December 2019 with 5504100000 HS code of viscose fiber staplers from www.simplyduty.com/import-calculator/.

Table C.11 Fabric import duty fees in percentage.

From/To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	10	10	0	10	0	0	0	0	0	20	0	0	10	0	25
2	8	0	0	8	10	0	8	8	8	8	20	10	0	0	0	25
3	0	0	0	0	10	0	0	0	0	0	20	10	0	0	0	25
4	0	0	0	0	10	0	0	0	0	0	20	0	0	10	0	25
5	8	10	10	8	0	0	8	8	8	8	20	10	8	10	0	25
6	8	0	0	8	10	0	8	8	8	8	20	10	0	0	0	25
7	0	10	10	0	10	0	0	0	0	0	20	0	0	10	0	25
8	0	10	10	0	10	0	0	0	0	0	20	0	0	10	0	25
9	0	10	10	0	10	0	0	0	0	0	20	0	0	10	0	25
10	0	10	10	0	10	0	0	0	0	0	20	0	0	10	0	25
11	0	10	10	0	10	0	0	0	0	0	0	0	0	10	0	25
12	0	10	10	0	10	0	0	0	0	0	20	0	0	10	0	25
13	0	10	10	0	10	0	0	0	0	0	20	0	0	10	0	25
14	8	0	0	8	10	0	8	8	8	8	20	10	0	0	0	25
15	0	0	0	0	10	0	0	0	0	0	20	10	0	0	0	25
16	0	8.5	8.3	8	10	0	0	0	0	0	20	10	0	8.5	0	0

Remarks: 1-16 refer to manufacturing locations in Austria, China(Nanjing), Indonesia, Great Britain, The United States, Thailand, Germany, Italy, Poland, Lithuania, Tunisia, Egypt, Turkey, China(Shanghai), Bangladesh, and India, respectively; and data are retrieved in December 2019 with 6006320000 HS code of viscose fabrics from www.simplyduty.com/import-calculator/.

Table C.12 T-shirt import duty fees in percentage.

From/To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
2	12	0	0	12	28	0	12	12	12	12	0	0	12	0	0	0
3	9.6	0	0	9.6	28	0	9.6	9.6	9.6	9.6	0	0	9.6	0	0	0
4	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
5	12	18	0	12	0	0	12	12	12	12	0	0	12	18	0	0
6	12	0	0	12	28	0	12	12	12	12	0	0	12	0	0	0
7	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
8	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
9	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
10	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
11	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
12	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
13	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
14	12	0	0	12	28	0	12	12	12	12	0	0	12	0	0	0
15	0	18	0	0	28	0	0	0	0	0	0	0	0	18	0	0
16	9.6	18	0	9.6	28	0	9.6	9.6	9.6	9.6	0	0	9.6	18	0	0

Remarks: 1-16 refer to manufacturing locations in Austria, China(Nanjing), Indonesia, Great Britain, The United States, Thailand, Germany, Italy, Poland, Lithuania, Tunisia, Egypt, Turkey, China(Shanghai), Bangladesh, and India, respectively; and data are retrieved in December 2019 with 6114300000 HS code of viscose t-shirts from www.simplyduty.com/import-calculator/.

Table C.13 Used garment import duty fees in percentage.

From/To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	5.3	0	0	5.3	0	30	5.3	5.3	5.3	5.3	20	35	0	0	0	25
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5.3	14	35	5.3	0	30	5.3	5.3	5.3	5.3	20	35	5.3	14	0	25
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	14	35	0	0	30	0	0	0	0	20	0	0	14	0	25
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	5.3	0	0	5.3	0	30	5.3	5.3	5.3	5.3	20	35	0	0	0	25
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Remarks: 1-16 refer to manufacturing locations in Austria, China(Nanjing), Indonesia, Great Britain, The United States, Thailand, Germany, Italy, Poland, Lithuania, Tunisia, Egypt, Turkey, China(Shanghai), Bangladesh, and India, respectively; and data are retrieved in December 2019 with 63090000 HS code of used garments from www.simplyduty.com/import-calculator/.

Appendix D: Study 3.2 Example of Calculated Supply Chain Cost and CO2e

Fiber location	Fabric location	Garment location	Market location	Fi price	...	Gar transport	Gar duty	Gar Truck from port	Landed cost		Fab visit transport	Gar visit transport	Fab visit employee	Gar visit employee	Fab visit hotel	Gar visit hotel	Firm interest	Firm landed cost		Worn price	Worn truck to port	Worn insurance	Worn transport	Worn duty	Worn truck from port	Worn landed cost
1	1	1	5	1,236.66	...	584.544829	3,954.94	7.95	17,987.48		291.70	291.70	831.20	831.20	72	72	116.62	20,493.90		950.77	7.95	44.98	664.9363	88.44	12.30	22,263.27
1	1	2	5	1,236.66	...	647.152465	3,231.13	7.95	14,696.98		583.40	1,914.64	1,662.40	3,324.81	144	122	158.93	22,607.15		950.77	7.95	44.98	664.9363	88.44	12.30	24,376.52
1	1	3	5	1,236.66	...	738.113444	3,039.12	7.95	13,824.12		583.40	1,449.24	1,662.40	3,324.81	144	140	151.86	21,279.83		950.77	7.95	44.98	664.9363	88.44	12.30	23,049.20
1	1	4	5	1,236.66	...	504.063433	3,777.33	7.95	17,180.05		583.40	667.62	1,662.40	2,216.54	144	217	126.69	22,797.71		950.77	7.95	44.98	664.9363	88.44	12.30	24,567.07
1	1	5	5	1,236.66	...	0	0.00	0.00	13,827.63		583.40	2,019.92	1,662.40	3,324.81	144	139	116.99	21,818.15		950.77	7.95	44.98	664.9363	88.44	12.30	23,587.51
1	1	6	5	1,236.66	...	752.020255	2,898.58	7.95	13,185.18		583.40	1,246.73	1,662.40	2,770.67	144	93	141.86	19,827.25		950.77	7.95	44.98	664.9363	88.44	12.30	21,596.61
1	1	7	5	1,236.66	...	494.658794	4,045.07	7.95	18,397.25		583.40	220.00	1,662.40	1,662.40	144	0	122.54	22,792.00		950.77	7.95	44.98	664.9363	88.44	12.30	24,561.37
1	1	8	5	1,236.66	...	557.720695	3,591.57	7.95	16,335.59		583.40	434.63	1,662.40	1,662.40	144	97	115.33	21,034.75		950.77	7.95	44.98	664.9363	88.44	12.30	22,804.12
1	1	9	5	1,236.66	...	547.029722	2,949.60	7.95	13,417.11		583.40	457.90	1,662.40	1,662.40	144	50	98.93	18,076.14		950.77	7.95	44.98	664.9363	88.44	12.30	19,845.51
1	1	10	5	1,236.66	...	568.227264	3,017.52	7.95	13,725.88		583.40	477.75	1,662.40	2,216.54	144	94	105.64	19,009.62		950.77	7.95	44.98	664.9363	88.44	12.30	20,778.98
1	1	11	5	1,236.66	...	557.720695	3,235.85	7.95	14,718.43		583.40	832.94	1,662.40	2,770.67	144	76	118.72	20,906.57		950.77	7.95	44.98	664.9363	88.44	12.30	22,675.94
1	1	12	5	1,236.66	...	711.032943	2,768.62	7.95	12,594.40		583.40	710.45	1,662.40	2,770.67	144	44	109.07	18,618.39		950.77	7.95	44.98	664.9363	88.44	12.30	20,387.76
1	1	13	5	1,236.66	...	663.317109	2,957.40	7.95	13,452.59		583.40	485.88	1,662.40	2,216.54	144	53	108.97	18,706.77		950.77	7.95	44.98	664.9363	88.44	12.30	20,476.14
1	1	14	5	1,236.66	...	647.152465	3,329.53	7.95	15,144.33		583.40	1,064.78	1,662.40	3,324.81	144	167	155.05	22,245.76		950.77	7.95	44.98	664.9363	88.44	12.30	24,015.13
1	1	15	5	1,236.66	...	726.158624	2,746.85	7.95	12,495.41		583.40	1,414.11	1,662.40	3,324.81	144	102	138.21	19,864.33		950.77	7.95	44.98	664.9363	88.44	12.30	21,633.70
1	1	16	5	1,236.66	...	686.516117	3,386.68	7.95	15,404.15		583.40	1,106.09	1,662.40	3,324.81	144	74	147.76	22,446.61		950.77	7.95	44.98	664.9363	88.44	12.30	24,215.98
1	2	1	5	1,236.66	...	584.544829	3,408.80	7.95	15,504.72		1,914.64	583.40	3,324.81	1,662.40	122	144	151.00	23,406.96		950.77	7.95	44.98	733.8541	243.26	3.22	25,390.99
1	2	2	5	1,236.66	...	647.152465	1,924.21	7.95	8,755.62		957.32	957.32	1,662.40	1,662.40	61	61	92.70	14,209.76		950.77	7.95	44.98	733.8541	243.26	3.22	16,193.79
1	2	3	5	1,236.66	...	738.113444	1,905.63	7.95	8,671.16		1,914.64	1,449.24	3,324.81	3,324.81	122	140	134.08	19,080.73		950.77	7.95	44.98	733.8541	243.26	3.22	21,064.76
1	2	4	5	1,236.66	...	504.063433	3,005.92	7.95	13,673.15		1,914.64	667.62	3,324.81	2,216.54	122	217	145.36	22,281.12		950.77	7.95	44.98	733.8541	243.26	3.22	24,265.15
1	2	5	5	1,236.66	...	0	0.00	0.00	10,453.44		1,914.64	2,019.92	3,324.81	3,324.81	122	139	140.19	21,438.80		950.77	7.95	44.98	733.8541	243.26	3.22	23,422.82
...	...	...	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...

Figure D.1 Example of supply chain cost calculation.

Fiber location	Fabric location	Garment location	Market location	Fi NREU	...	Fab heat	Fab landfill	Fab sample delivery	Fab truck to port	Fab transport	Fab truck from port	Gar electric	Gar landfill	Gar sample delivery	Gar truck to port	Gar trar	Gar truck from port	Landed CO2e		Fab visit	Gar visit	Firm CO2e		Worn truck to port	Worn transport	Worn truck from port	Worn CO2e
1	1	1	5	1,015.56	...	236.70	268.80	0.34	0.00	0.00	0.00	162.58	228.12	0.17	31.67	136.35	21.70	5,542.79		356.74	356.74	6,256.27		60.25	378.75	87.80	6,783.06
1	1	2	5	1,015.56	...	236.70	268.80	0.34	38.94	235.93	27.22	898.02	228.12	13.39	22.17	217.88	21.70	6,665.57		356.74	2,714.19	9,736.49		60.25	378.75	87.80	10,263.28
1	1	3	5	1,015.56	...	236.70	268.80	0.34	38.94	179.02	9.53	669.72	228.12	17.51	7.77	258.40	21.70	6,392.91		356.74	3,567.75	10,317.40		60.25	378.75	87.80	10,844.19
1	1	4	5	1,015.56	...	236.70	268.80	0.34	38.94	84.18	2.95	474.02	228.12	1.61	2.41	104.92	21.70	5,921.06		356.74	312.34	6,590.14		60.25	378.75	87.80	7,116.93
1	1	5	5	1,015.56	...	236.70	268.80	0.34	38.94	167.65	26.68	507.50	228.12	12.38	0.00	0.00	0.00	5,943.48		356.74	2,975.54	9,275.76		60.25	378.75	87.80	9,802.55
1	1	6	5	1,015.56	...	236.70	268.80	0.34	38.94	193.95	15.13	584.51	228.12	14.08	13.78	263.04	21.70	6,335.46		356.74	3,077.27	9,769.47		60.25	378.75	87.80	10,296.26
1	1	7	5	1,015.56	...	236.70	268.80	0.34	0.00	67.64	0.00	618.23	228.12	0.00	14.24	104.78	21.70	6,016.91		356.74	15.48	6,389.12		60.25	378.75	87.80	6,915.92
1	1	8	5	1,015.56	...	236.70	268.80	0.34	0.00	60.73	0.00	375.95	228.12	0.16	15.19	118.02	21.70	5,782.08		356.74	359.94	6,498.75		60.25	378.75	87.80	7,025.55
1	1	9	5	1,015.56	...	236.70	268.80	0.34	0.00	75.23	0.00	1,107.56	228.12	0.22	25.70	116.06	21.70	6,536.79		356.74	386.12	7,279.65		60.25	378.75	87.80	7,806.44
1	1	10	5	1,015.56	...	236.70	268.80	0.34	0.00	125.56	0.00	116.42	228.12	0.33	21.42	120.62	21.70	5,596.37		356.74	533.97	6,487.08		60.25	378.75	87.80	7,013.87
1	1	11	5	1,015.56	...	236.70	268.80	0.34	38.94	25.08	15.08	546.10	228.12	3.26	12.26	119.25	21.70	5,971.99		356.74	955.75	7,284.48		60.25	378.75	87.80	7,811.28
1	1	12	5	1,015.56	...	236.70	268.80	0.34	38.94	33.65	13.17	494.90	228.12	5.68	10.34	140.27	21.70	5,948.98		356.74	1,096.75	7,402.47		60.25	378.75	87.80	7,929.26
1	1	13	5	1,015.56	...	236.70	268.80	0.34	38.94	31.70	0.06	873.10	228.12	3.78	0.04	139.18	21.70	6,298.83		356.74	681.12	7,336.68		60.25	378.75	87.80	7,863.47
1	1	14	5	1,015.56	...	236.70	268.80	0.34	38.94	230.86	2.31	898.02	228.12	13.67	1.73	217.88	21.70	6,615.43		356.74	2,821.05	9,793.21		60.25	378.75	87.80	10,320.01
1	1	15	5	1,015.56	...	236.70	268.80	0.34	38.94	158.80	22.69	608.13	228.12	11.66	18.50	241.96	21.70	6,312.71		356.74	2,600.34	9,269.78		60.25	378.75	87.80	9,796.57
1	1	16	5	1,015.56	...	236.70	268.80	0.34	38.94	115.41	25.57	1,558.55	228.12	10.20	20.72	206.67	21.70	7,188.09		356.74	2,215.77	9,760.60		60.25	378.75	87.80	10,287.39
1	2	1	5	1,015.56	...	236.70	268.80	26.78	27.26	230.86	38.86	162.58	228.12	0.17	31.67	136.35	21.70	6,667.44		2,714.19	356.74	9,738.36		60.25	605.22	61.48	10,465.31
1	2	2	5	1,015.56	...	236.70	268.80	26.78	0.00	0.00	0.00	898.02	228.12	13.39	22.17	217.88	21.70	7,191.14		2,714.19	2,714.19	12,619.52		60.25	605.22	61.48	13,346.47
1	2	3	5	1,015.56	...	236.70	268.80	26.78	27.26	67.78	9.53	669.72	228.12	17.51	7.77	258.40	21.70	7,097.65		2,714.19	3,567.75	13,379.59		60.25	605.22	61.48	14,106.54
1	2	4	5	1,015.56	...	236.70	268.80	26.78	27.26	286.45	2.95	474.02	228.12	1.61	2.41	104.92	21.70	6,939.31		2,714.19	312.34	9,965.84		60.25	605.22	61.48	10,692.80
1	2	5	5	1,015.56	...	236.70	268.80	26.78	27.26	267.90	26.68	507.50	228.12	12.38	0.00	0.00	0.00	6,859.70		2,714.19	2,975.54	12,549.43		60.25	605.22	61.48	13,276.39
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	..	...	...	...	..	...	...	...	...

Figure D.2 Example of supply chain CO2e calculation.

Appendix E: Study 3.2 Additional Results of Low Cost and CO2e Supply chain Analysis

Table E.1 Descriptive cost data of three computational scopes for each market warehouse for one batch production of 1,800 t-shirts.

	US landed cost	DE landed cost	CN landed cost	US firm cost	DE firm cost	CN firm cost	US worn cost	DE worn cost	CN worn cost
Min value, €	5,078	4,025	3,668	9,253	7,768	8,505	11,180	9,229	10,080
Max value, €	20,284	17,808	19,009	28,333	25,322	26,551	29,284	26,273	28,126
Average value, €	11,505	9,218	10,214	18,679	16,373	17,381	20,592	17,866	18,949
Median value, €	11,105	9,076	10,173	18,533	16,057	17,146	20,513	17,545	18,621
90th percentile value, €	7,629	5,915	5,996	15,094	12,947	13,944	17,068	14,453	15,628
95th percentile value, €	7,113	5,542	5,581	14,070	11,955	12,996	15,956	13,349	14,710
99th percentile value, €	6,188	4,694	4,932	10,425	8,706	9,460	12,583	10,173	11,116
€ cost increase at 90th percentile	2,551	1,890	2,328	5,841	5,179	5,439	5,889	5,224	5,548
€ cost increase at 95th percentile	2,036	1,517	1,913	4,817	4,187	4,490	4,776	4,120	4,630
€ cost increase at 99th percentile	1,110	669	1,264	1,171	938	955	1,403	945	1,037
% cost increase at 90th percentile	50	47	63	63	67	64	53	57	55
% cost increase at 95th percentile	40	38	52	52	54	53	43	45	46
% cost increase at 99th percentile	22	17	34	13	12	11	13	10	10
% increase at 16th rank	21	16	34	13	12	11	12	10	10
% increase at 1536th rank	299	342	418	206	226	212	162	185	179

Remarks: US= the United States, DE= Germany, CN= China (Shanghai).

Table E.2 Descriptive carbon dioxide equivalent (CO2e) data of three computational scopes for each market warehouse for one batch production of 1,800 t-shirts.

	US landed CO2e	DE landed CO2e	CN landed CO2e	US firm CO2e	DE firm CO2e	CN firm CO2e	US worn CO2e	DE worn CO2e	CN worn CO2e
Min value, kgCO2e	5,543	5,408	5,575	6,256	6,122	6,288	6,706	6,174	6,902
Max value, kgCO2e	10,107	10,030	9,982	15,935	15,858	15,712	16,734	16,445	16,054
Average value, kgCO2e	8,295	8,233	8,269	11,378	11,316	11,351	11,906	11,673	11,807
Median value, kgCO2e	8,472	8,409	8,447	11,638	11,602	11,666	12,228	11,979	12,139
90^{th} percentile value, kgCO2e	6,812	6,755	6,761	8,674	8,568	8,747	9,108	8,721	9,407
95^{th} percentile value, kgCO2e	6,429	6,383	6,440	8,252	8,147	8,291	8,678	8,259	8,857
99^{th} percentile value, kgCO2e	5,958	5,875	6,032	6,670	6,572	6,754	7,107	6,722	7,426
kgCO2e increase at 90^{th} percentile	1,269	1,347	1,187	2,417	2,447	2,459	2,402	2,547	2,505
kgCO2e increase at 95^{th} percentile	886	975	866	1,996	2,025	2,003	1,972	2,085	1,955
kgCO2e increase at 99^{th} percentile	415	467	458	413	450	466	401	548	523
% kgCO2e increase at 90^{th} percentile	23	25	21	39	40	39	36	41	36
% kgCO2e increase at 95^{th} percentile	16	18	16	32	33	32	29	34	28
% kgCO2e increase at 99^{th} percentile	7	9	8	7	7	7	6	9	8
% increase at 16^{th} rank	7	9	8	7	7	7	6	9	8
% increase at 1536^{th} rank	82	85	79	155	159	150	150	166	133

Remark: US= the United States, DE= Germany, CN= China (Shanghai).

Plotting of Cost and CO2e Factor Breakdown

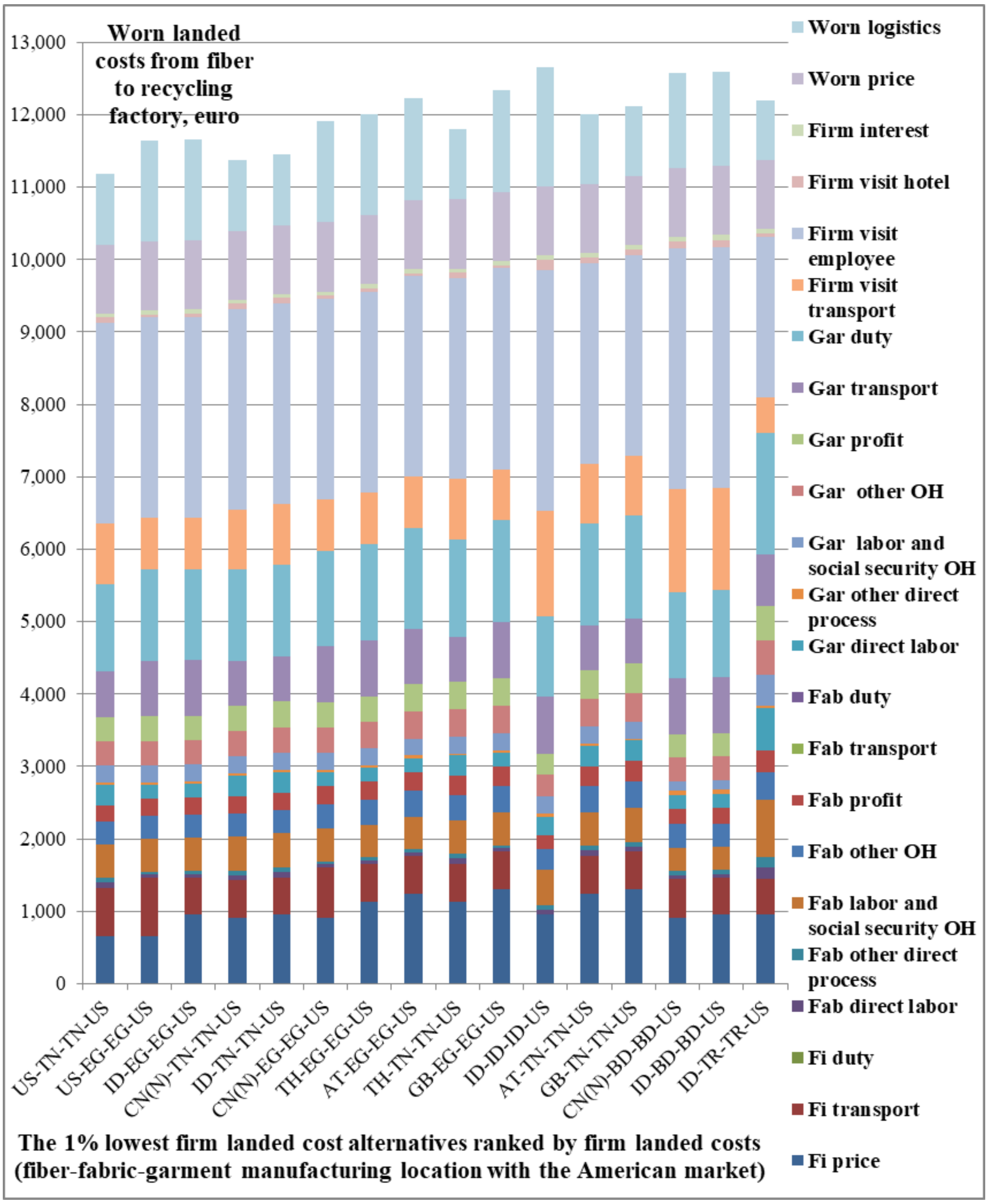

Figure E.1 Cost-factor graph plotting of 1,800 t-shirt worn costs ranked by the 1% lowest firm cost alternatives with the warehouse in the United States.

Remarks: Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, OH= overheads; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, US= the United States, TH= Thailand, TN= Tunisia, EG= Egypt, TR= Turkey, BD= Bangladesh.

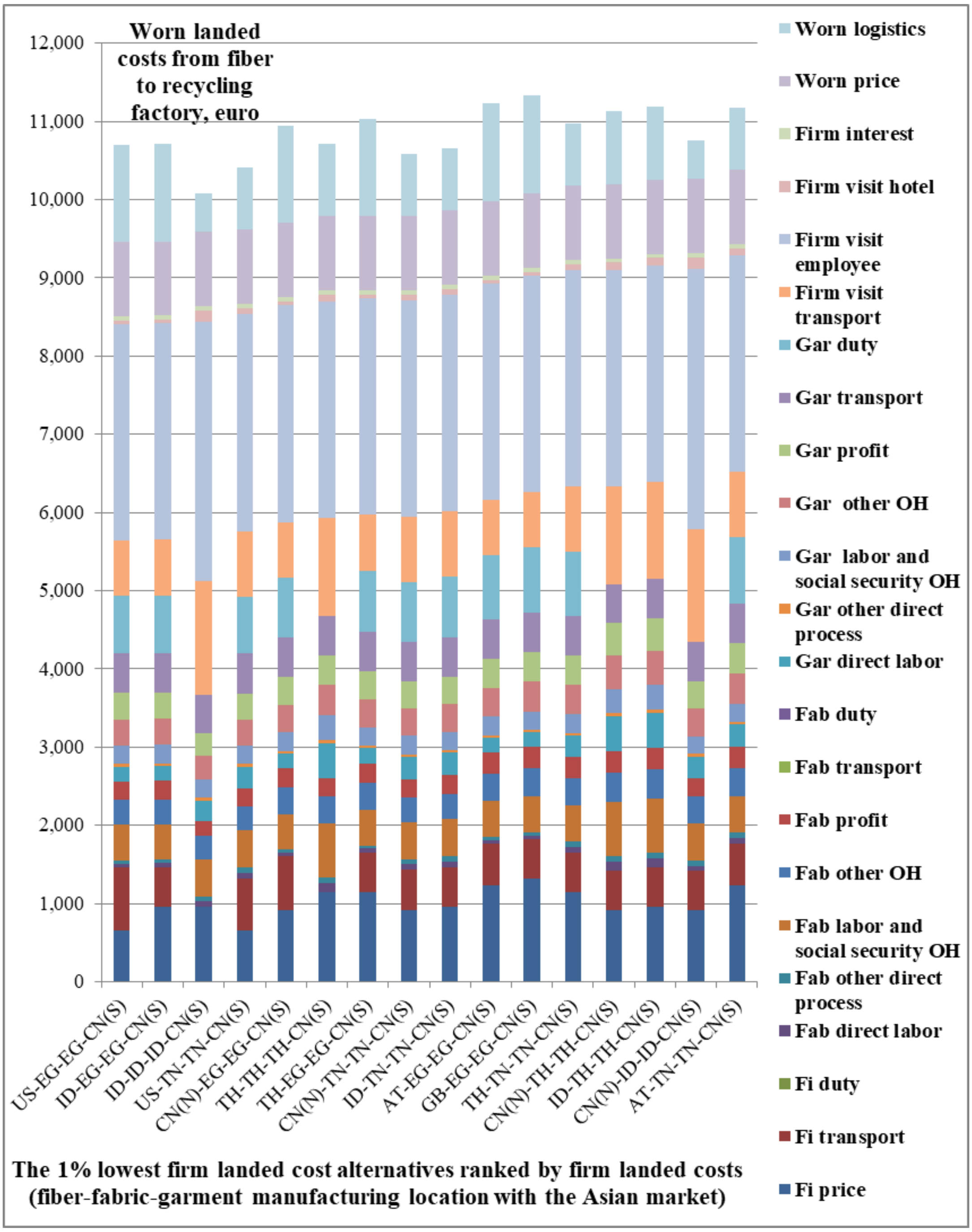

Figure E.2 Cost-factor graph plotting of 1,800 t-shirt worn costs ranked by the 1% lowest firm cost alternatives with the warehouse in China.

Remarks: Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, OH= overheads; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, TH= Thailand, TN= Tunisia, EG= Egypt, CN(S)= China (Shanghai).

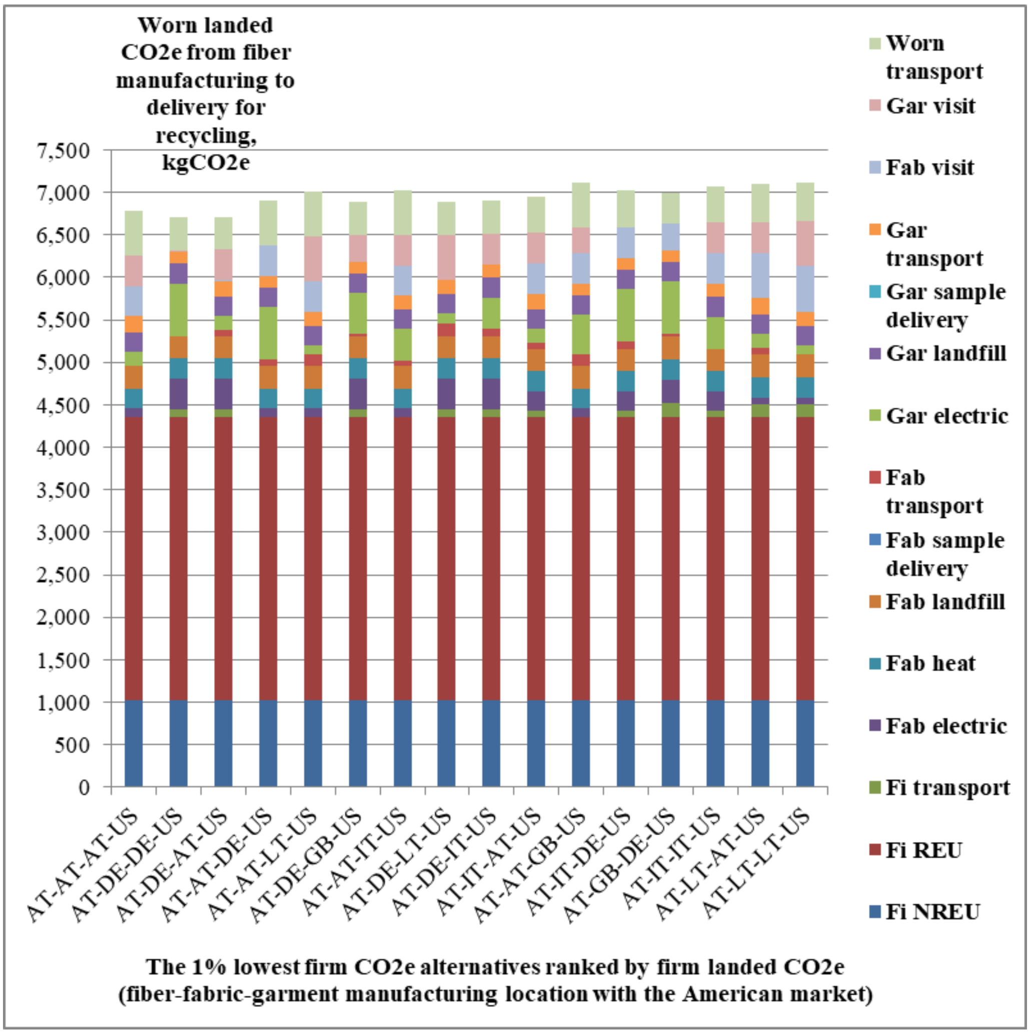

Figure E.3 Carbon dioxide equivalent (CO2e)-factor graph plotting of 1,800 t-shirt worn CO2e ranked by the 1% lowest firm CO2e alternatives with the warehouse in the United States.

Remarks: Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, NREU= non-renewable energy use, REU= renewable energy use; AT= Austria, GB= Great Britain, US= the United States, DE= Germany, IT= Italy, LT= Lithuania.

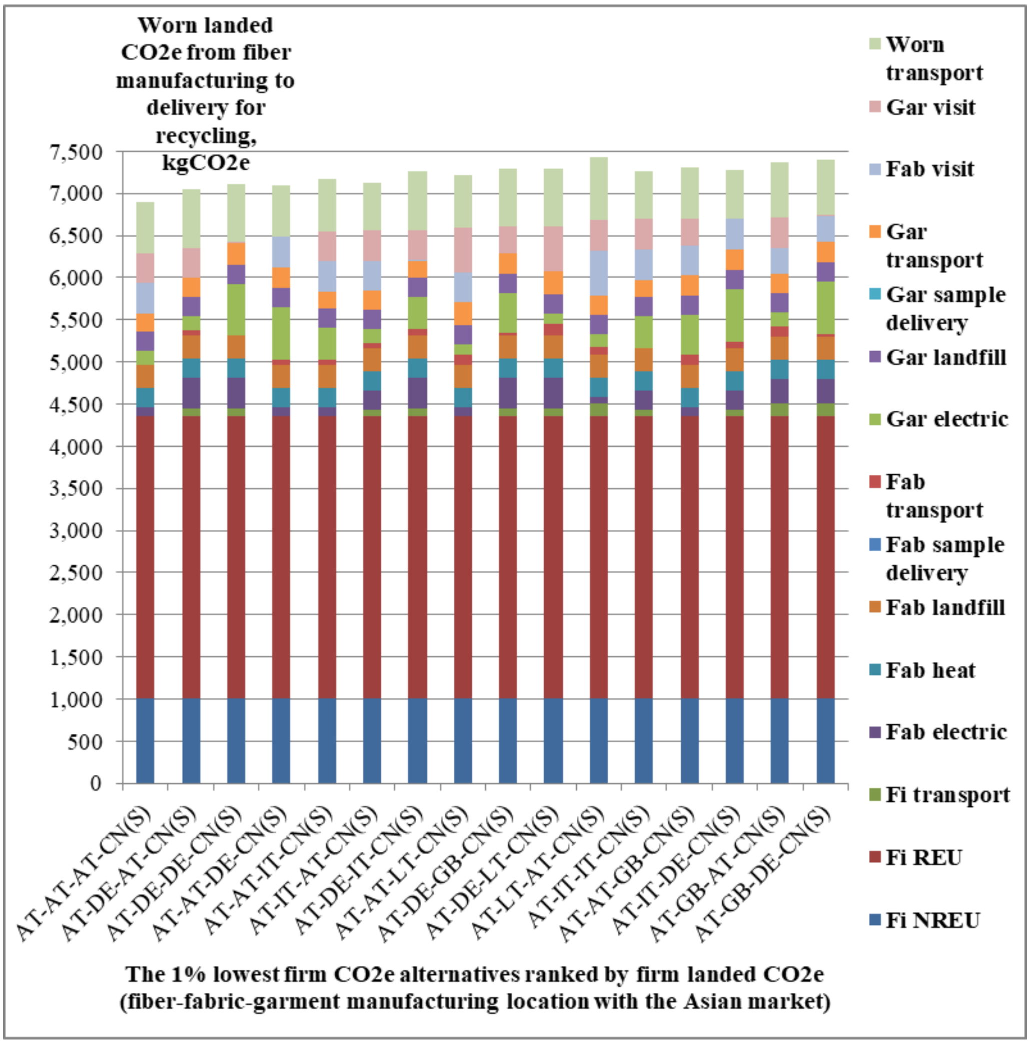

Figure E.4 Carbon dioxide equivalent (CO2e)-factor graph plotting of 1,800 t-shirt worn CO2e ranked by the 1% lowest firm CO2e alternatives with the warehouse in China.

Remarks: Fi= fiber, Fab= fabric, Gar= garment, Worn= worn garment, NREU= non-renewable energy use, REU= renewable energy use; AT= Austria, GB= Great Britain, DE= Germany, IT= Italy, LT= Lithuania, CN(S)= China (Shanghai).

Cost and CO2e Scatter Plotting

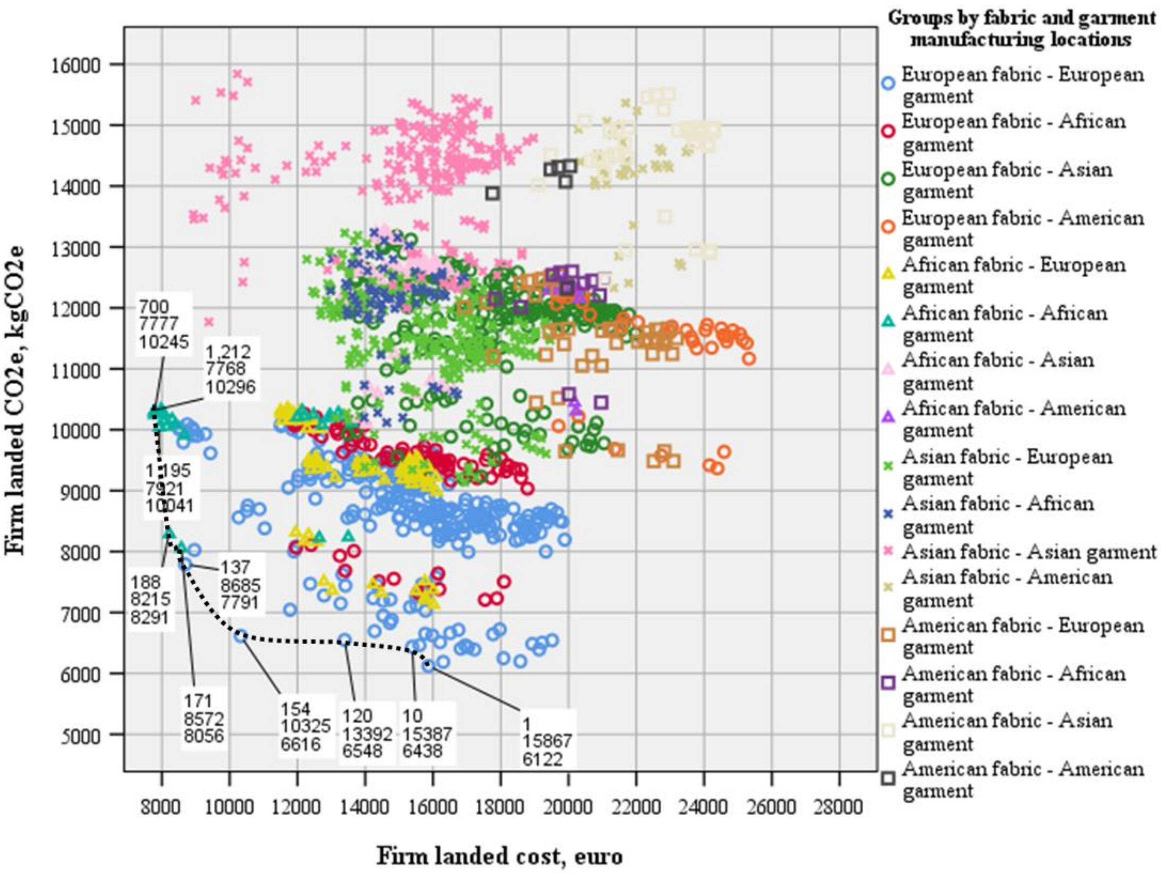

Figure E.5 Firm cost and carbon dioxide equivalents (CO2e) scatter plotting of alternatives with the warehouse in Germany for one batch of 1,800 t-shirt manufacturing.

Remarks: Pareto frontier alternatives are shown with information of their alternative numbers, costs, and CO2e from top to bottom; Alternative numbers and fiber, fabric, and garment manufacturing locations are 1212 (US-EG-EG), 700 (ID-EG-EG), 1195 (US-TN-TN), 188 (AT-EG-EG), 171 (AT-TN-TN), 137 (AT-PL-PL), 154 (AT-LT-LT), 120 (AT-IT-IT), 10 (AT-AT-LT), and 1 (AT-AT-AT); AT= Austria, ID= Indonesia, US= the United States, IT= Italy, PL= Poland, LT= Lithuania, TN= Tunisia, EG= Egypt.

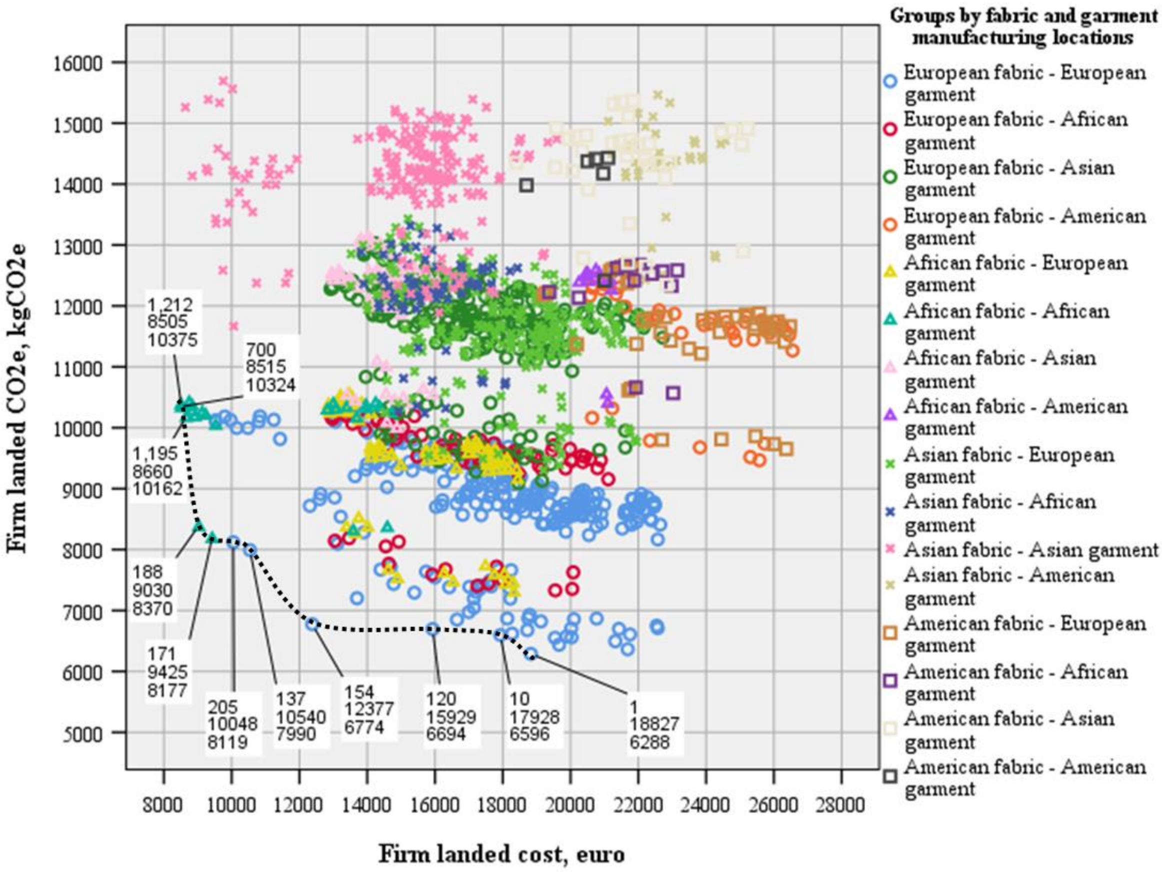

Figure E.6 Firm cost and carbon dioxide equivalents (CO2e) scatter plotting of alternatives with the warehouse in China for one batch of 1,800 t-shirt manufacturing.

Remarks: Pareto frontier alternatives are shown with information of their alternative numbers, costs, and CO2e from top to bottom; Alternative numbers and fiber, fabric, and garment manufacturing locations are 1212 (US-EG-EG), 700 (ID-EG-EG), 1195 (US-TN-TN), 188 (AT-EG-EG), 171 (AT-TN-TN), 205 (AT-TR-TR), 137 (AT-PL-PL), 154 (AT-LT-LT), 120 (AT-IT-IT), 10 (AT-AT-LT), and 1 (AT-AT-AT); AT= Austria, ID= Indonesia, US= the United States, IT= Italy, PL= Poland, LT= Lithuania, TN= Tunisia, EG= Egypt, TR= Turkey.

Sensitivity Analysis

Table E.3 Sensitive cost factors giving new lowest cost alternatives for each warehouse and computational scope for factor value changes at all locations at a time.

Factors and their coefficients giving new lowest cost alternatives	US firm (US-TN-TN)*	DE landed (ID-ID-ID)*	DE firm (US-EG-EG)*	DE worn (US-EG-EG)*	CN(S) firm (US-EG-EG)*
Fiber 0.75	ID-EG-EG	0	ID-EG-EG	ID-EG-EG	ID-EG-EG
Fiber 1.25	0	CN(N)-BD-BD	0	0	0
Helper wage 1.25	0	CN(N)-BD-BD	0	0	0
Operator wage 1.25	US-EG-EG	CN(N)-BD-BD	0	0	0
Manager wage 1.25	0	CN(N)-BD-BD	0	0	0
Social security 1.25	0	CN(N)-BD-BD	0	0	0
Water 1.25	0	CN(N)-BD-BD	0	0	0
Firm transport visit cost 0.75	0	0	0	0	ID-ID-ID
Firm manager visit cost 0.75	0	0	0	0	ID-ID-ID

Remarks: * refers to the original lowest cost alternatives before the changes; Names of the lowest cost alternatives refer to fiber, fabric, and garment manufacturing locations; CN(N)= China (Nanjing), ID= Indonesia, US= the United States, DE= Germany, TN= Tunisia, EG= Egypt, BD= Bangladesh, CN(S)= China (Shanghai).

Table E.4 Sensitive manufacturing-cost factors giving new lowest cost alternatives for each warehouse and computational scope after factor value changes at each location at a time.

Factors and their coefficients	US landed (ID-ID-ID)*	US firm (US-TN-TN)*	US worn (US-TN-TN)*	DE landed (ID-ID-ID)*	DE firm (US-EG-EG)*	DE worn (US-EG-EG)*	CN firm (US-EG-EG)*	CN worn (ID-ID-ID)*
Fiber AT 0.75	0	0	0	0	AT-EG-EG	AT-EG-EG	AT-EG-EG	0
Fiber CN(N) 0.75	CN(N)-BD-BD	CN(N)-TN-TN	CN(N)-TN-TN	CN(N)-BD-BD	CN(N)-EG-EG	CN(N)-EG-EG	CN(N)-EG-EG	0
Fiber ID 0.75	0	ID-EG-EG	ID-TN-TN	0	ID-EG-EG	ID-EG-EG	ID-EG-EG	0
Fiber ID 1.25	CN(N)-BD-BD	0	0	CN(N)-BD-BD	0	0	0	US-TN-TN
Fiber US 0.75	0	0	0	US-TN-TN	0	0	0	0
Fiber US 1.25	0	ID-EG-EG	CN(N)-TN-TN	0	ID-EG-EG	ID-EG-EG	ID-EG-EG	0
Fiber TH 0.75	0	TH-EG-EG	0	TH-BD-BD	TH-EG-EG	TH-EG-EG	TH-EG-EG	0
Helper, operator, manager wages, and social security ID 1.25	0	0	0	CN(N)-BD-BD	0	0	0	0
Helper, operator, manager wages, and social security TN 1.25	0	US-EG-EG	0	0	0	0	0	0
Helper, operator, manager wages, and social security EG 0.75	0	US-EG-EG	0	0	0	0	0	0
Helper, operator, and manager wages BD 0.75	0	0	0	CN(N)-BD-BD	0	0	0	0
Operator and manager wages ID 0.75	0	0	0	0	0	0	ID-ID-ID	0
Operator wage PL 0.75	0	0	0	0	0	US-PL-PL	0	0
Operator wage TN 0.75	0	0	0	US-TN-TN	US-TN-TN	0	US-TN-TN	0
Operator and manager wages EG 1.25	0	0	0	0	0	0	ID-ID-ID	0
Manager wage DE 0.75	0	0	0	0	0	0	ID-ID-ID	0
Electricity, water, fabric employee certificate, fabric test ID 1.25	0	0	0	CN(N)-BD-BD	0	0	0	0
Electricity, water, fabric test BD 0.75	0	0	0	CN(N)-BD-BD	0	0	0	0

Remarks: * refers to the original lowest cost alternatives before the changes; AT= Austria, CN(N)= China (Nanjing), ID= Indonesia, US= the United States, TH= Thailand, DE= Germany, PL= Poland, TN= Tunisia, EG= Egypt, BD= Bangladesh, CN= China (Shanghai).

Table E.5 Sensitive firm-cost factors giving new lowest cost alternatives for each warehouse and computational scope after factor value changes at each location at a time.

Factors and their coefficients	US firm (US-TN-TN)*	US worn (US-TN-TN)*	DE firm (US-EG-EG)*	DE worn (US-EG-EG)*	CN firm (US-EG-EG)*	CN worn (ID-ID-ID)*
Firm transportation visit cost ID 0.75	0	0	0	0	ID-ID-ID	0
Firm transportation visit cost ID 1.25	0	0	0	0	0	US-TN-TN
Firm transportation visit cost TN 0.75	0	0	US-TN-TN	0	US-TN-TN	0
Firm transportation visit cost TN 1.25	US-EG-EG	0	0	0	0	0
Firm transportation visit cost EG 0.75	US-EG-EG	0	0	0	0	0
Firm transportation visit cost EG 1.25	0	0	US-TN-TN	0	ID-ID-ID	0
Firm manager visit cost ID 0.75	ID-ID-ID	0	0	0	ID-ID-ID	0
Firm manager visit cost ID 1.25	0	0	0	0	0	US-TN-TN
Firm manager visit cost TH 0.75					TH-TH-TH	TH-TH-TH
Firm manager visit cost TN 0.75	0	0	US-TN-TN	US-TN-TN	US-TN-TN	US-TN-TN
Firm manager visit cost TN 1.25	US-EG-EG	US-EG-EG	0	0	0	0
Firm manager visit cost EG 0.75	US-EG-EG	US-EG-EG	0	0	0	US-EG-EG
Firm manager visit cost EG 1.25	0	0	US-TN-TN	US-TN-TN	ID-ID-ID	0

Remarks: * refers to the original lowest cost alternatives before the changes; ID= Indonesia, US= the United States, TH= Thailand, DE= Germany, TN= Tunisia, EG= Egypt, TR= Turkey, CN = China (Shanghai).

Table E.6 Sensitive transportation-cost factors giving new lowest cost alternatives for each market and computational scope after factor value changes everywhere and at each location.

Factors and their coefficients	US landed (ID-ID-ID)*	US firm (US-TN-TN)*	US worn (US-TN-TN)*	DE landed (ID-ID-ID)*	DE firm (US-EG-EG)*	DE worn (US-EG-EG)*	CN firm (US-EG-EG)*	CN worn (ID-ID-ID)*
Ship everywhere 0.75	0	US-EG-EG	0	CN(N)-BD-BD	0	0	0	0
Ship everywhere 1.25	0	0	0	0	ID-EG-EG	ID-EG-EG	ID-ID-ID	0
Ship and truck everywhere 0.75	0	US-EG-EG	0	CN(N)-BD-BD	0	0	0	0
Ship and truck everywhere 1.25	0	0	0	0	ID-EG-EG	ID-EG-EG	ID-ID-ID	0
Ship from CN(N) 0.75	0	CN(N)-TN-TN	CN(N)-TN-TN	CN(N)-BD-BD	CN(N)-EG-EG	CN(N)-EG-EG	CN(N)-EG-EG	0
Ship from ID 0.75	0	ID-EG-EG	0	ID-BD-BD	ID-EG-EG	ID-EG-EG	ID-EG-EG	0
Ship from ID 1.25	0	0	0	CN(N)-BD-BD	0	0	0	0
Ship from US 0.75	0	US-EG-EG	0	US-EG-EG	0	0	0	0
Ship from US 1.25	0	ID-EG-EG	CN(N)-TN-TN	0	ID-EG-EG	ID-EG-EG	ID-EG-EG	0
Ship from TN 1.25	0	US-EG-EG	0	0	0	0	0	0
Ship from EG 0.75	0	US-EG-EG	0	0	0	0	0	0
Ship from EG 1.25	0	0	0	0	0	0	ID-ID-ID	0
Ship from BD 0.75	0	0	0	CN(N)-BD-BD	0	0	0	0
Ship to US 0.75	0	US-EG-EG	0	0	0	0	0	0
Ship to DE 0.75	0	0	0	CN(N)-BD-BD	0	0	0	0
Ship to TN 0.75	0	0	0	US-TN-TN	US-TN-TN	0	US-TN-TN	US-TN-TN
Ship to TN 1.25	US-EG-EG	0	0	0	0	0	0	
Ship to EG 0.75	0	US-EG-EG	US-EG-EG	US-EG-EG	0	0	0	0
Ship to EG 1.25	0	0	0	0	US-TN-TN	ID-EG-EG	ID-ID-ID	0
Ship to BD 0.75	0	0	0	CN(N)-BD-BD	0	0	0	0

Remarks: * refers to the original lowest cost alternatives before the changes; CN(N)= China (Nanjing), ID= Indonesia, GB= Great Britain, US= the United States, DE= Germany, TN= Tunisia, EG= Egypt, TR= Turkey, CN= China (Shanghai), BD= Bangladesh.

Table E.7 Sensitive duty-cost factors giving new lowest cost alternatives for each warehouse and computational scope after factor value changes everywhere and at each location.

Factors and their coefficients	US firm (US-TN-TN)*	DE landed (ID-ID-ID)*	CN firm (US-EG-EG)*
Existing garment duty everywhere 1.25	0	CN(N)-BD-BD	ID-ID-ID
Garment duty from TN 0.75	0	0	US-TN-TN
Garment duty from TN 1.25	US-EG-EG	0	0
Garment duty from EG 0.75	US-EG-EG	0	0
Garment duty from EG 1.25	0	0	ID-ID-ID
Garment duty to DE 1.25	0	CN(N)-BD-BD	0
Garment duty to CN(S) 1.25	0	0	ID-ID-ID

Remarks: * refers to the original lowest cost alternatives before the changes; CN(N)= China (Nanjing), ID= Indonesia, US= the United States, DE= Germany, TN= Tunisia, EG= Egypt, CN= China (Shanghai), BD= Bangladesh.

Table E.8 Sensitive CO2e factors giving new lowest CO2e alternatives for each warehouse and computational scope after factor value changes everywhere and at each location.

Factors and their coefficients	US firm (AT-AT-AT)*	US worn (AT-DE-DE)*	DE firm (AT-AT-AT)*	DE worn (AT-DE-DE)*	CN firm (AT-AT-AT)*
CO2 truck 0.75	0	AT-DE-AT	0	AT-DE-AT	0
CO2 ship 0.75	0	AT-DE-AT	0	0	0
Flight for factory visit everywhere 0.75	0	AT-AT-AT	0	AT-DE-AT	0
Flight for factory visit everywhere 1.25	AT-DE-DE	0	AT-DE-DE	0	AT-DE-DE
Flight for factory visit AT 0.75	0	AT-AT-AT	0	AT-DE-AT	0
Flight for factory visit AT 1.25	AT-DE-DE	0	AT-DE-DE	0	AT-DE-DE

Remarks: * refers to the original lowest CO2e alternatives before the changes; AT= Austria, US= the United States, DE= Germany, CN= China (Shanghai).

Scenario Analysis

Table E.9 Scenario analysis of duty fees imitating trade war with equal duty fees in all locations showing new lowest cost alternatives for each warehouse and computational scope.

Factors and their coefficients	US landed (ID-ID-ID)*	US firm (US-TN-TN)*	US worn (US-TN-TN)*	DE landed (ID-ID-ID)*	CN firm (US-EG-EG)*	CN worn (ID-ID-ID)*
0% garment duty	0	0	0	0	0	US-TN-TN
5% garment duty	ID-ID-US	0	0	CN(N)-BD-BD	ID-ID-ID	0
10% garment duty	ID-ID-US	US-US-US	US-US-US	CN(N)-BD-BD	ID-ID-ID	0
10% worn-garment duty	0	0	CN(N)-BD-BD	0	0	0
20% garment duty	ID-ID-US	US-US-US	US-US-US	CN(N)-BD-BD	ID-ID-ID	0
20% worn-garment duty	0	0	CN(N)-BD-BD	0	0	0
30% garment duty	ID-ID-US	US-US-US	US-US-US	CN(N)-BD-BD	ID-ID-ID	0
30% worn-garment duty	0	0	CN(N)-BD-BD	0	0	0
40% garment duty	ID-ID-US	US-US-US	US-US-US	CN(N)-BD-BD	ID-ID-ID	0
40% worn-garment duty	0	0	CN(N)-BD-BD	0	0	0

Remarks: * refers to the original lowest cost alternatives before the changes; CN(N)= China (Nanjing), ID= Indonesia, US= the United States, DE= Germany, TN= Tunisia, CN= China (Shanghai), BD= Bangladesh.

Appendix F: Publications

Article information [article ranking by ABS2018: 4*-1 / AJG2018: 4*-1 / ABDC2019: A*-C / CNRS2019: 1*-4 / FNEGE2019: 1*-4]

Articles in Refereed Academic Journals

Sirilertsuwan, P., Ekwall, D., & Hjelmgren, D. (2018). Proximity Manufacturing for Enhancing Clothing Supply Chain Sustainability. *The International Journal of Logistics Management*, 29(4), 1346-1378. https://doi.org/10.1108/IJLM-09-2017-0233. [1/1/A/3/3]

Sirilertsuwan, P., Hjelmgren, D., & Ekwall, D. (2019). Exploring Current Enablers and Barriers for Sustainable Proximity Manufacturing. *Journal of Fashion Marketing and Management: An International Journal*, 23(4), 551-571. https://doi:10.1108/JFMM-09-2018-0114. [-/1/-/-/-]

Working Papers in Preparation for Submission

Sirilertsuwan, P., Thomassey, S., & Zeng, X. A Strategic Location Decision-Making Approach for Multi-tier Supply Chain Sustainability: Local and Global Production of Apparel.

Sirilertsuwan, P., Chen, Y., Wang, L. The Effects of Worldwide Living Wage Laws for Manufacturing Workers on Landed Costs of Local, Nearshore, and Offshore Products.

Presentations and Participation at International Academic Conferences

Sirilertsuwan, P., Thomassey, S., & Zeng, X. *Beyond Inclusive Organization and Supplier Inclusion: How Workers Living Wages Influence Manufacturing Locations*. Peer-reviewed conference paper submitted to the Operations and Supply Chain Management (OSCM) division with the participation on the Doctoral Consortium, the Academy of Management (AOM) Annual Meeting. Boston, The United States (US), August, 2019.

Sirilertsuwan, P., Thomassey, S., & Zeng, X. *Environmental and Social Indicators: Sustainable Manufacturing and Supplier Location Decisions*. Working paper presented at the NOFOMA (Nordic logistics and supply chain) conference. Oslo, Norway, June, 2019.

Sirilertsuwan, P., Thomassey, S., & Zeng, X. *A Manufacturing-Decision Model for Sustainability Improvement*. Working paper submitted to the OSCM division for the participation on the Doctoral Consortium, the AOM Annual Meeting. Chicago, US, August, 2018.

Sirilertsuwan, P., Hjelmgren, D., & Ekwall, D. *Proximity Manufacturing for Sustainable Clothing Supply Chain: Benefits and Barriers*. Peer-reviewed conference paper presented at the NOFOMA conference 2018. Kolding, Denmark, June, 2018.

Sirilertsuwan, P., Ekwall, D., & Hjelmgren, D. *Fast Fashion Sustainable Supply Chain: Benefits and Factors of Proximity Manufacturing*. Peer-reviewed conference paper presented at the NOFOMA conference 2017. Lund, Sweden, June, 2017.