SUPPLY CHAIN ANALYSIS FOR SUSTAINABLE PRODUCTS

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by

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DECLARATION

I hereby declare that:

1. The work presented in this thesis is original and has been carried out by me as a student of IIT Delhi.

2. To the best of my knowledge, the work presented in this thesis has not been submitted, either in whole or in part, to any other institution for the award of any degree or diploma.

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6. All sources of information, including data, ideas, and text, have been duly acknowledged and appropriately cited in the thesis.

7. The use of artificial intelligence (AI) tools (if any), including large language models, has been appropriately disclosed. All analysis interpretations, and conclusions presented in this thesis are my own. Alternatively, I declare that no AI tools, including large language models, have been used in the preparation of this thesis.

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This is to certify that the thesis entitled "**Supply Chain Analysis for Sustainable Products**" being submitted by **Mr. Prashant Kumar** to Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a record of original research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard.

The results contained in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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Prashant Kumar

Abstract

The growing focus on sustainability, along with increased awareness of traditional and organic alternatives, has revitalized interest in India's informal sectors that produce eco-friendly and culturally significant products like jaggery and bamboo-based products. Despite their ecological compatibility and significance for livelihoods, these industries are not sufficiently recognized in mainstream markets and insufficiently examined in academic research. This study aims to analyze products from the unorganized sector through three interrelated dimensions: manufacturing and supply chain barriers, consumer behavior and subscription intentions, and logistics optimization, thereby offering a thorough understanding of the challenges and opportunities related to revitalizing sustainable, livelihood-focused product systems. The main objective is to produce practical insights to assist policymakers, entrepreneurs, and sustainability practitioners in improving market access, strengthening producer livelihoods, and encouraging environmentally responsible consumption.

The first dimension examines the supply, production, and marketing barriers that restrict the expansion of informal jaggery and bamboo sectors. The study employs the Fuzzy Best-Worst Method (FBWM) for prioritizing barriers and the Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) for interrelationship study, systematically assessing challenges across different crucial dimensions: raw material and sourcing, manufacturing and processing, transportation and logistics, consumer awareness and marketing, and institutional and regulatory factors. The findings highlight major barriers, such as insufficient raw material availability, restricted technological support, insufficient logistical infrastructure, and inadequate market visibility, exposing the interconnections among these barriers that intensify production inefficiencies and market underdevelopment. This analytical framework offers a quantitative and rigorous method for analyzing uncertainty and systemic complexity, representing a methodological progress in the examination of informal production systems and delivering specific insights for policy development, capacity enhancement, and value chain strengthening.

The second dimension examines consumer perceptions, motivations, and subscription intentions for sustainable jaggery and bamboo-based products. The study utilizes a mixed-methods approach to analyze behavioral factors such as functional value, consumer awareness, hedonic motivation, perceived barriers, and attitude. Employing Logistic Regression,

Structural Equation Modeling (SEM), and mediation analysis, both direct and indirect effects on subscription willingness are explored, providing a comprehensive understanding of how cultural traditions, sustainability awareness, and perceived product authenticity collectively influence consumer adoption behavior. The results establish a behavioral basis for encouraging the repeated purchase of traditional eco-friendly products, connecting sustainability with consumer loyalty and lifestyle integration. The study discusses the nuanced effects of attitudinal and motivational factors on subscription intentions by examining mediating methods, offering practical guidance for the development of marketing interventions, awareness campaigns, and community engagement strategies that promote continuous sustainable consumption.

The third analytical dimension examines logistical and distributional constraints that limit market connection and equal access. The study employs facility location optimization models to determine the optimal number and location of sales points for jaggery and bamboo-based products, thereby effectively addressing urban and semi-urban demand. The framework integrates transportation expenses, capacity limitations, and demand fluctuations to optimize coverage while reducing operational costs and product waste. This component presents a data-driven decision support system that connects production and consumer behavior via effective logistics planning. The optimization results also guide initiatives for formalizing informal supply chains, enhancing accessibility for producers, and expanding market reach while promoting sustainable livelihoods.

The study establishes a complete, systems-oriented framework by integrating three analytical dimensions: barrier evaluation, behavioral analysis, and logistics optimization, thereby linking production, market dynamics, and geographic distribution. This multidisciplinary approach constitutes one of the first comprehensive studies of informal-sector products, offering both theoretical and practical strategies for improving resilience, marketability, and sustainability. The methodology is applicable to different livelihood sectors, such as millet, handcrafts, and other organic products, addressing differences in consumer behavior, operational barriers, and strategic logistics planning.

This research is novel due to its integrated approach, analyzing production barriers, consumer adoption, and distribution optimization simultaneously. This study integrates consumer behavior and supply chain restrictions into a livelihood-centered sustainability framework, unlike previous research that focuses just on one of these areas.

The study identifies strategies for incorporating unorganized producers/processors into formal value chains, emphasizing the necessity of policy interventions that promote sustainable production, efficient marketing, and informed consumer engagement while maintaining cultural authenticity. Focusing on value enhancement, branding, and effective logistics offers a strategy for transforming local livelihoods into sustainable businesses. The results strongly support several Sustainable Development Goals (SDGs), specifically SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

The results provide a reference framework for policymakers, nonprofit organizations, entrepreneurs, and sustainability practitioners, offering recommendation for inclusive policy formulation, successful marketing strategies, and strong market connections for sustainable products. The integrated method shows that environmental sustainability, economic viability, and cultural preservation can be concurrently attained in informal-sector value chains.

This thesis signifies an important attempt to revitalize traditional, livelihood-based sectors in India. By integrating barrier analysis, behavioral analysis, and facility location optimization, it offers both theoretical depth and practical solutions for improving sustainability, customer engagement, and producer empowerment. The study emphasizes that sustainable development in emerging countries must combine ecological responsibility with inclusivity, equity, and the preservation of traditional knowledge, providing a framework for integrating cultural heritage with modern innovation to create a sustainable future.

Keywords: Jaggery and Associated Products, Bamboo-Based Products, Informal Sector, Sustainable Consumption, Manufacturing Barriers, Consumer Behavior, Subscription Intention, Mediation Analysis, Facility Location Optimization, Supply Chain Resilience, Value Chain Integration, Sustainable Development Goals.

सारांश

सततता पर बढ़ती प्रवृत्ति और पारंपरिक एवं जैविक विकल्पों के प्रति जागरूकता ने भारत के अनौपचारिक क्षेत्रों में निर्मित पारिस्थितिक रूप से अनुकूल और सांस्कृतिक रूप से महत्वपूर्ण उत्पादों जैसे गुड़ और बाँस आधारित उत्पादों में नवीन रुचि पैदा की है। यद्यपि ये उद्योग पर्यावरणीय अनुकूलता और आजीविका के लिए महत्वपूर्ण हैं, फिर भी ये मुख्यधारा के बाजारों में पर्याप्त रूप से मान्यता प्राप्त नहीं हैं और अकादमिक शोध में इनकी पर्याप्त जांच नहीं हुई है। यह अध्ययन अनियोजित क्षेत्र के उत्पादों का विश्लेषण तीन आपस में जुड़े पहलुओं-निर्माण और आपूर्ति श्रृंखला बाधाएँ, उपभोक्ता व्यवहार और सदस्यता इच्छाएँ, और लॉजिस्टिक अनुकूलन-के माध्यम से करता है, जिससे सतत और आजीविका-केंद्रित उत्पाद प्रणालियों के पुनरुत्थान से जुड़ी चुनौतियों और अवसरों की संपूर्ण समझ प्राप्त होती है। मुख्य उद्देश्य नीति निर्माता, उद्यमी और स्थिरता कार्यकर्ता के लिए व्यावहारिक दिशा-निर्देश तैयार करना है, जिससे बाजार तक पहुँच बढ़ाने, उत्पादक आजीविका मजबूत करने और पर्यावरणीय रूप से जिम्मेदार उपभोग को प्रोत्साहित किया जा सके।

अध्ययन का पहला आयाम उन उत्पादन और आपूर्ति श्रृंखला बाधाओं की जांच करता है, जो अनौपचारिक गुड़ और बाँस उद्योगों के विस्तार को सीमित करती हैं। इस अध्ययन में बाधाओं को प्राथमिकता देने के लिए संकरित श्रेष्ठ-न्यूनतम विधि का उपयोग किया गया और आपसी संबंधों का विश्लेषण करने के लिए निर्णय-मूल्यांकन प्रयोगशाला की संकरित पद्धति का उपयोग किया गया। अध्ययन ने इन बाधाओं का व्यवस्थित मूल्यांकन पाँच महत्वपूर्ण आयामों में किया है: कच्चा माल और स्रोत, निर्माण और प्रसंस्करण, परिवहन और लॉजिस्टिक्स, उपभोक्ता जागरूकता और विपणन, तथा संस्थागत और नियामक कारक। परिणामों से प्रमुख बाधाएँ उजागर होती हैं, जैसे अपर्याप्त कच्चा माल, सीमित तकनीकी सहायता, अपर्याप्त लॉजिस्टिक आधारभूत संरचना और कमजोर बाज़ार दृश्यता। ये बाधाएँ आपस में जुड़ी हुई हैं, जो उत्पादन में अक्षम्यताओं और बाजार के अधिविकास को बढ़ाती हैं। यह विश्लेषणात्मक रूपरेखा अनिश्चितता और प्रणालीगत जटिलताओं के विश्लेषण के लिए सघन और मात्रात्मक तरीका प्रदान करती है, जो अनौपचारिक उत्पादन प्रणालियों के अध्ययन में एक पद्धतिगत प्रगति का प्रतिनिधित्व करती है और नीति विकास, क्षमता संवर्धन और मूल्य श्रृंखला सुदृढ़ीकरण के लिए विशिष्ट दिशानिर्देश प्रदान करती है।

अध्ययन का दूसरा आयाम उपभोक्ता की धारणाओं, प्रेरणाओं और सदस्यता इच्छाओं का विश्लेषण करता है। यह अध्ययन मिश्रित विधियों का उपयोग करता है और व्यवहारिक कारकों जैसे कार्यात्मक मूल्य, उपभोक्ता जागरूकता, सुखद प्रेरणा, बाधाएँ और दृष्टिकोण का मूल्यांकन करता है। लॉजिस्टिक

प्रतिगमन, संरचनात्मक समीकरण मॉडलिंग और मध्यस्थता विश्लेषण के माध्यम से सदस्यता की इच्छा पर प्रत्यक्ष और अप्रत्यक्ष प्रभावों का अध्ययन किया गया है। यह विश्लेषण दर्शाता है कि सांस्कृतिक परंपराएँ, स्थिरता जागरूकता और उत्पाद की प्रामाणिकता मिलकर उपभोक्ता को अपनाने के व्यवहार को प्रभावित करती हैं। परिणाम पारंपरिक और पर्यावरणीय रूप से अनुकूल उत्पादों की पुनरावृत्ति खरीद को बढ़ावा देने का व्यवहारिक आधार प्रदान करते हैं और स्थिरता को उपभोक्ता निष्ठा और जीवनशैली के एकीकरण से जोड़ते हैं। मध्यस्थता विश्लेषण द्वारा व्यवहार और प्रेरक कारकों के सूक्ष्म प्रभावों को उजागर किया गया है, जिससे मार्केटिंग हस्तक्षेप, जागरूकता अभियान और सामुदायिक सहभागिता रणनीतियों के लिए व्यावहारिक मार्गदर्शन मिलता है।

अध्ययन का तीसरा आयाम लॉजिस्टिक और वितरण बाधाओं का समाधान करता है, जो बाजार से जुड़ाव और समान पहुँच को सीमित करती हैं। बिक्री केंद्र अनुकूलन मॉडल का उपयोग करके गुड़ और बाँस आधारित उत्पादों के लिए बिक्री केंद्रों की सर्वोत्तम संख्या और स्थान निर्धारित किए गए हैं, ताकि शहरी और अर्ध-शहरी मांग को प्रभावी ढंग से पूरा किया जा सके। इस ढांचे में परिवहन लागत, क्षमता प्रतिबंध और मांग में उतार-चढ़ाव को शामिल किया गया है ताकि कवरेज अधिकतम और संचालन लागत व उत्पाद अपशिष्ट न्यूनतम हो। यह आयाम एक डेटा-संचालित निर्णय समर्थन प्रणाली प्रस्तुत करता है, जो उत्पादन और उपभोक्ता व्यवहार को प्रभावी लॉजिस्टिक्स योजना के माध्यम से जोड़ता है। अनुकूलन परिणाम अनौपचारिक आपूर्ति श्रृंखलाओं को औपचारिक बनाने, उत्पादकों के लिए पहुँच बढ़ाने और बाजार विस्तार को बढ़ावा देने के लिए मार्गदर्शन भी प्रदान करते हैं।

तीनों आयामों-बाधा मूल्यांकन, व्यवहार विश्लेषण और लॉजिस्टिक अनुकूलन-को एकीकृत करके यह अध्ययन एक संपूर्ण, प्रणालीगत दृष्टिकोण प्रस्तुत करता है, जो उत्पादन, बाजार गतिशीलता और भौगोलिक वितरण को जोड़ता है। यह बहुविषयक दृष्टिकोण अनौपचारिक-क्षेत्र उत्पादों का समग्र विश्लेषण करने वाले पहले प्रयासों में से एक है, जो सैद्धांतिक और व्यावहारिक रणनीतियाँ प्रदान करता है और उत्पादकता, बाजार क्षमता और स्थिरता में सुधार के लिए मार्गदर्शन करता है। इस पद्धति को अन्य आजीविका-आधारित क्षेत्रों जैसे बाजरा, हस्तशिल्प और जैविक उत्पादों में लागू किया जा सकता है।

इस शोध की नवीनता इसके एकीकृत दृष्टिकोण में निहित है, जो उत्पादन बाधाओं, उपभोक्ता अपनाने और वितरण अनुकूलन को एक साथ विश्लेषित करता है। यह अध्ययन उपभोक्ता व्यवहार और आपूर्ति श्रृंखला प्रतिबंधों को आजीविका-केंद्रित स्थिरता ढांचे में जोड़ता है, जबकि पहले के शोध अक्सर केवल एक पहलू पर ध्यान केंद्रित करते थे।

अध्ययन अनियोजित उत्पादकों/प्रसंस्कर्ताओं को औपचारिक मूल्य श्रृंखला में शामिल करने की रणनीतियाँ सुझाता है और नीति हस्तक्षेप की आवश्यकता पर जोर देता है, जो स्थायी उत्पादन, कुशल विपणन और सूचित उपभोक्ता सहभागिता को बढ़ावा देते हुए सांस्कृतिक प्रामाणिकता बनाए रखें। मूल्य संवर्धन, ब्रांडिंग और प्रभावी लॉजिस्टिक्स पर ध्यान केंद्रित करना स्थानीय आजीविकाओं को स्थायी व्यवसायों में बदलने की दिशा में मार्गदर्शन करता है। परिणाम कई सतत विकास लक्ष्यों का समर्थन करते हैं, विशेष रूप से सुसंगत कार्य और आर्थिक विकास, उद्योग, नवाचार और आधारभूत संरचना, जिम्मेदार उपभोग और उत्पादन, और जलवायु कार्रवाई।

परिणाम नीति निर्माताओं, गैर-लाभकारी संगठनों, उद्यमियों और स्थिरता कार्यकर्ताओं के लिए संदर्भ ढांचे प्रदान करते हैं, जो समावेशी नीति निर्माण, प्रभावी विपणन रणनीतियों और मजबूत बाजार कनेक्शन के लिए मार्गदर्शन करता है। यह एकीकृत दृष्टिकोण दिखाता है कि पर्यावरणीय स्थिरता, आर्थिक व्यवहार्यता और सांस्कृतिक संरक्षण को अनौपचारिक मूल्य श्रृंखलाओं में समान रूप से प्राप्त किया जा सकता है।

अंततः, यह शोध भारत में पारंपरिक, आजीविका-केंद्रित क्षेत्रों को पुनर्जीवित करने का एक महत्वपूर्ण प्रयास है। बाधा विश्लेषण, व्यवहार विश्लेषण और बिक्री केंद्र अनुकूलन को एकीकृत करके यह सैद्धांतिक गहराई और व्यावहारिक समाधान दोनों प्रदान करता है, जो स्थिरता, उपभोक्ता सहभागिता और उत्पादक सशक्तिकरण में सुधार करते हैं। अध्ययन इस बात पर जोर देता है कि उभरती अर्थव्यवस्थाओं में सतत विकास केवल पर्यावरणीय जिम्मेदारी तक सीमित नहीं होना चाहिए, बल्कि इसमें समावेशिता, समानता और पारंपरिक ज्ञान का संरक्षण भी शामिल होना चाहिए, जिससे सांस्कृतिक विरासत और आधुनिक नवाचार का सामंजस्य बनाकर स्थायी भविष्य का मार्ग प्रशस्त किया जा सके।

मुख्य शब्द: गुड़ और सम्बंधित उत्पाद, बाँस आधारित उत्पाद, अनौपचारिक क्षेत्र, सतत उपभोग, निर्माण बाधाएँ, उपभोक्ता व्यवहार, सदस्यता इच्छाएँ, बिक्री केंद्र अनुकूलन, आपूर्ति श्रृंखला स्थिरता, मूल्य श्रृंखला एकीकरण, सतत विकास लक्ष्य।

Contents

Chapter 1 Introduction 1
1.1. Background of the Study 1
1.2. Thesis Organization and Summaries 7
Chapter 2 Literature Review and Research Gaps 10
2.1. Literature Review 10
2.1.1. Supply Chain Management in Rural and Informal Sectors 15
2.1.2. Alignment of Products with Sustainable Development Goals 20
2.1.3. Barriers in Manufacturing and Processing and Market Access 23
2.1.4. Market Potential, Consumer Behavior, and Subscription-Based Models 27
2.1.5. Transportation and Distribution in Resource-Constrained Settings 30
2.2. Research Gaps 33
2.3. Research Problem and Objectives 36
2.4. Scope of the Thesis 38
Chapter 3 Methodology 40
3.1. Conceptual framework 40
3.1.1. Supply chain barriers analysis 41
3.1.2. Understanding consumer behavior and subscription intentions 45
3.1.3. Optimization of Logistics for Improved Market Access 49
3.2. Connectivity between Objectives 51
3.3. Analysis techniques for objective solution 54
3.3.1. Techniques for analysing barriers 54
3.3.2. Multinomial Logistic Regression 59
3.3.3. Structural Equation Modeling 61
3.3.4. Facility Location Model 62
Chapter 4 Analysis of Supply Chain Barriers 67
4.1. Literature Review 70
4.1.1. Jaggery and Associated Products 70
4.1.2. Bamboo Based Products 79
4.2. Case Study 83
4.2.1. Survey Design 83
4.2.2. Data Collection 84
4.2.3. Qualitative Data Processing and Analysis 86
4.2.4. Ranking using FBWM 87
4.2.4.1. Jaggery and Associated Products 87

4.2.4.2. Bamboo Based Products 90
4.2.5. Modelling using FDEMATEL 90
4.2.5.1. Jaggery and Associated Products 90
4.2.5.2. Bamboo Based Products 91
4.2.6. Results and Discussion 92
4.2.6.1. Jaggery and Associated Products 92
4.2.6.2. Bamboo Based Products 96
4.2.7. Implications and Sustainability Realization 100
4.2.7.1. Jaggery and Associated Products 100
4.2.7.2. Bamboo Based Products 106
4.2.8. Conclusion and Future Scope 108
4.2.8.1. Jaggery and Associated products 108
4.2.8.2. Bamboo Based Products 110
Chapter 5 Analysis of Consumer Behavior and Subscription Intentions 113
5.1. Analysis of Consumer Behavior 114
5.1.1. Context of the problem 116
5.1.1.1. Jaggery and Associated Products 116
5.1.1.2. Bamboo Based Products 118
5.1.2. Case Study 120
5.1.2.1. Jaggery and Associated Products 120
5.1.2.2. Bamboo Based Products 133
5.2. Analysis of Subscription Intentions 144
5.2.1. Context and Hypothesis Development 146
5.2.1.1. Jaggery and Associated Products 146
5.2.1.2. Bamboo Based Products 152
5.2.2. Case Study 158
5.2.2.1. Jaggery and Associated Products 158
5.2.2.2. Bamboo Based Products 169
Chapter 6 Optimization of Logistics for Improved Market Access 183
6.1. Context of the Study 185
6.1.1. Current Status of Jaggery in the Indian Context 185
6.1.2. Significance of Bamboo-Based Products in the Indian Context 186
6.1.3. Challenges with jaggery and bamboo-based products 186
6.1.4. Rationale for Optimizing Selling Centres 187
6.2. Mathematical Modeling 189
6.3. Case Study 195

6.3.1. Data Collection 195
6.3.2. Analysis 196
6.3.3. Results and Discussion 198
6.3.4. Sensitivity Analysis 203
6.3.5. Implications 206
6.3.6. Conclusion and Future Scope 207
Chapter 7 Conclusion and Future Scope 210
7.1. Key Findings 210
7.1.1. Analysis of Supply-Chain Barriers (RO1) 210
7.1.2. Analysis of Consumer Behavior and Subscription Intentions (RO2) 211
7.1.3. Optimization of Logistics for Improved Market Access (RO3) 212
7.2. Study Limitations 214
7.3. Future Works 217
References 222
Appendix 246

List of Tables

Table 2- 1 Literature Research of MCDM Techniques 26

Table 4- 1 List of barriers (Jaggery and Associated Products) 78
Table 4- 2 List of barriers (Bamboo-Based Products) 88
Table 4- 3 Best and Worst criterion for FBWM (Jaggery and Associated Products) 90
Table 4- 4 Best and Worst criterion for FBWM (Bamboo Based Products) 90
Table 4- 5 Prominence and Relation matrix of jaggery and associated products 91
Table 4- 6 Prominence and Relation matrix of bamboo-based products 92
Table 4- 7 Ranking of barriers using FBWM 93
Table 4- 8 Prioritization matrix for FBWM 98
Table 4- 9 Implications of the study 107

Table 5- 1 Model Parameters of the Significant Variables 125
Table 5- 2: Parameter estimate of the significant independent variables 125
Table 5- 3: Advisories for government 128
Table 5- 4: Advisories for industries and local units 129
Table 5- 5: Advisories for consumers 130
Table 5- 6: PEST analysis for promoting bamboo's global competitiveness 136
Table 5- 7: Significant variables with MLR analysis 137
Table 5- 8: Constructs Evolved from Literature Study 146
Table 5- 9 Literature evidence on the constructs under study 157
Table 5- 10 Cross Loading, Composite Reliability (CR) and Average Variance Extracted (AVE) 162
Table 5- 11 Heterotrait - Monotrait (HTMT) Fornell Larcker (FL) discriminant validity measurement 162
Table 5- 12 Structural model results for direct path 163
Table 5- 13 Cross Loading, Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE) 172
Table 5- 14 Fornell-Larcker discriminant validity measurement 173
Table 5- 15 Heterotrait-Monotrait (HTMT) discriminant validity measurement 173
Table 5- 16 Structural model results for direct path 173
Table 5- 17 Interpretations for significant variables 174
Table 5- 18 Mediation results 177
Table 5- 19 Implications of the study corresponding to the valid hypothesis 180

Table 6- 1 Sensitivity Analysis for Jaggery and Associated Products 203
Table 6- 2 Sensitivity Analysis for Bamboo Based Products 204

List of Figures

Fig. 2- 1 Annual scientific production on the concept of "Fuzzy Logic and Barrier Study"... 11
Fig. 2- 2 Annual scientific production on the concept of "Multinomial Logistic Regression and Consumer Behavior" 12
Fig. 2- 3 Annual scientific production on the concept of "Subscription and Consumer Behavior" 13
Fig. 2- 4 Annual scientific production on the concept of "SEM and Consumer Behavior" 14
Fig. 2- 5 Annual scientific production on the concept of "Facility Location Model and Warehouses/Selling Centres" 15
Fig. 2- 6 Overview of Supply Chain Management in Rural and Informal Sectors 20
Fig. 2- 7 Overview of product alignment with SDGs 22
Fig. 2- 8 Process of supply chain barriers analysis 25
Fig. 2- 9 Conceptual highlights of market and consumer study 30
Fig. 2- 10 Conceptual highlight of logistics network of informal products 33

Fig. 3- 1 Comprehensive Framework for Supply Chain Brriers Analysis 44
Fig. 3- 2 Comprehensive Framework for Studying Factors Influencing Product Usage 46
Fig. 3- 3 Comprehensive Framework for Studying Subscription Intentions 49
Fig. 3- 4 Comprehensive Outline for Logistics Network Study 50
Fig. 3- 5 Conceptual Framework for the flow of study 54

Fig. 4- 1 A Schematic of Jaggery Manufacturing 73
Fig. 4- 2 A Typical Indian Bamboo Supply Chain 80
Fig. 4- 3. Cause- Effect relationship plot (Jaggery and Associated Products) 95
Fig. 4- 4 Cause-Effect Interrelationship Model (Jaggery and Associated Products) 96
Fig. 4- 5: Causal-Effect Relationship Plot (Bamboo-Based Products) 99
Fig. 4- 6: Influence relationship map (Bamboo-Based Products) 100
Fig. 4- 7: Causal Barriers Sustainability Realizations 105
Fig. 4- 8: Effect Barriers Sustainability Realizations 105
Fig. 4- 9: Top causal-effect barriers and their mapping with SDGs 108
Fig. 4- 10: Top barriers and their SDGs realizations 108

Fig. 5- 1 Overview of flow of the study 118
Fig. 5- 2 Interlink between government, industries and consumers 127
Fig. 5- 3 Research Model 159
Fig. 5- 4 Constructs and Corresponding Items 159
Fig. 5- 5 Research Model (Bamboo Based Products) 170
Fig. 5- 6 Constructs with corresponding items 170
Fig. 5- 7 Mediation Analysis 176
Fig. 5- 8 Overall summary of the study, implications, and SDGs mapping 180

Fig. 6- 1 Schematic of a General Distribution Network 189
Fig. 6- 2 Optimal Locations for (a) Jaggery and Associated Products and (b) Bamboo Based Products 202

Fig. 6- 3 Graphical Representations of Sensitivity Analysis for Jaggery and Associated Products.....204
Fig. 6- 4 Graphical Representations of Sensitivity Analysis for Bamboo Based Products ..205