Major Research Project Report

on

BIOGAS INNOVATION TRANSFORMING WASTE MANAGEMENT INTO ECONOMIC OPPORTUNITIES

Submitted for the partial fulfilment of the requirements for the degree of

Master of Business Administration

in

Data Science and Analytics

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CERTIFICATE

This is to certify that the project titled "Biogas Innovation Transforming Waste Management into Economic Opportunities" submitted in partial fulfilment of the requirements for the Degree of Master of Business Administration by Suraj Bhandari at the University School of Management & Entrepreneurship, Delhi Technological University is a record of original research work carried out by her. Any material borrowed or referred to has been duly acknowledged.

Student

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This is to certify that the above-mentioned project titled " Biogas Innovation Transforming Waste Management into Economic Opportunities" submitted by Suraj Bhandari, Roll No. 23/UEMBA/12, has been carried out under my supervision.

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EXECUTIVE SUMMARY

The complexity and fragmentation of modern agri-food supply chains pose significant challenges to food safety, traceability, and sustainability. Traditional systems often fail to deliver real-time transparency, leading to inefficiencies, waste, and diminished consumer trust. This study proposes a blockchain-based framework for improving traceability across agricultural supply chains. Using a hybrid methodological approach combining the BWM (Best Worst Method), TISM (Total Interpretive Structural Modelling), and MICMAC analysis, this research identifies and ranks key technological, organizational, and environmental enablers influencing blockchain adoption. Results reveal that data transparency, government policy alignment, and stakeholder collaboration are critical drivers, while consumer trust and cost-efficiency emerge as dependent outcomes. The study provides a decision-support roadmap for policymakers, agribusiness firms, and technology developers to facilitate sustainable and secure food systems.

Keywords:

Blockchain, Agri-food supply chain, Traceability, Food security, Sustainability, Technology-Organization-Environment (TOE) framework

CHAPTER 1

1. Introduction

Global food systems are facing immense challenges driven by rising population pressures, climate change, food fraud, and the growing demand for transparency and sustainability. According to the Food and Agriculture Organization (FAO), nearly one-third of all food produced globally is lost or wasted. Furthermore, consumers are increasingly demanding visibility into how, where, and by whom their food is produced. In this context, modernizing agri-food supply chains through digital transformation is a critical imperative.

Blockchain technology has emerged as a transformative solution to address the transparency and traceability gaps that plague agri-food supply chains. With its core attributes of decentralization, immutability, and real-time data sharing, blockchain enables stakeholders to securely track agricultural products from farm to fork. The application of blockchain in traceability systems is expected to not only enhance food safety but also build trust among consumers, reduce fraud, and drive sustainability across the food ecosystem.

1.1 Problem Statement

Traditional traceability systems in agri-food supply chains are paper-based, fragmented, and prone to manipulation. These systems often lack the real-time capacity to trace product origin, manage recalls, and verify sustainability claims. As global trade expands and supply chains become more complex, these limitations expose stakeholders to financial, legal, and reputational risks. Despite the promise of blockchain, adoption remains limited due to technological, organizational, and policy-related barriers. There is a need for a comprehensive framework to identify and structure the enablers of blockchain adoption in agri-food traceability systems.

1.2 Research Objective

The main objective of this study is to develop a strategic framework for implementing blockchain-based traceability systems in agri-food supply chains. Specifically, this study aims to:

- Identify key technological, organizational, and environmental enablers influencing blockchain adoption.
- Prioritize these enablers using the Best Worst Method (BWM).
- Establish interrelationships among enablers using Total Interpretive Structural Modeling (TISM).
- Categorize enablers based on their driving and dependence power using MICMAC analysis.

1.3 Research Questions

To achieve the stated objectives, the study seeks to answer the following research questions:

- What are the key enablers for implementing blockchain in agri-food traceability systems?
- How can these enablers be prioritized for strategic planning?
- What are the hierarchical relationships among these enablers?
- Which enablers serve as drivers, linkages, or dependent outcomes in the blockchain adoption process?

1.4 Significance of the Study:

This study contributes to both academic literature and practical applications. Theoretically, it extends the Technology-Organization-Environment (TOE) framework by integrating multi-criteria decision-making tools to evaluate blockchain adoption. Practically, the findings provide actionable insights for policymakers, agribusiness firms, and technology providers seeking to implement blockchain-based traceability systems. The research also aligns with several United Nations Sustainable Development Goals (SDGs), including Goal 2 (Zero Hunger), Goal 12 (Responsible Consumption and Production), and Goal 16 (Peace, Justice, and Strong Institutions).

1.5 Scope and Delimitations

The scope of this study is limited to the use of blockchain for traceability in the agri-food sector. It does not explore other applications of blockchain such as financial transactions, smart insurance, or land records. The study focuses on enablers of adoption rather than barriers. Data collection is limited to expert opinions from academics, policymakers, and professionals with experience in agri-food, technology, and blockchain.

CHAPTER 2

2. Literature Review

This chapter offers a thorough analysis of the existing literature on blockchain applications in agri-food supply chains. It explores the evolution of food traceability systems, the potential of blockchain in overcoming traceability challenges, and the broader theoretical and technological contexts influencing adoption. The literature is reviewed across key dimensions: technological, organizational, and environmental, in alignment with the TOE framework.

2.1 Evolution of Food Traceability Systems

Traditional traceability systems in agri-food supply chains rely on centralized databases, manual documentation, and linear information flow. These systems are often slow, error-prone, and susceptible to tampering. Early innovations included barcoding and RFID tagging, but they lacked integration across actors. The food scandals of the 1990s and early 2000s, such as mad cow disease and the melamine milk scandal, underscored the urgent need for end-to-end traceability.

2.2 Blockchain Technology: Overview and Capabilities

Blockchain is a distributed ledger technology that records transactions across a peer-to-peer network. Its features include immutability, transparency, decentralization, and consensus mechanisms. In supply chains, blockchain allows each stakeholder to record and verify data in real time without requiring a central authority. Smart contracts can automate compliance checks, payments, and logistics workflows. Its application in agriculture includes farm-level data capture, quality certification, logistics tracking, and retail provenance.

2.3 Blockchain in Agri-Food Supply Chains

Studies highlight several benefits of blockchain in the agri-food sector:

- Enhanced food safety and recall management
- Reduced food fraud and adulteration
- Increased consumer trust through transparent labeling

- Streamlined certification and compliance processes
- Improved coordination among supply chain actors

Pilot projects such as IBM Food Trust (with Walmart) and Provenance (UK) have demonstrated successful implementations of blockchain in food systems, tracking items like pork, seafood, and organic vegetables. Despite these successes, scaling adoption remains a challenge due to interoperability, cost, and data standardization issues.

2.4 Technological Enablers and Challenges

Key technological enablers include:

- Internet of Things (IoT) integration for data capture
- Cloud computing for scalability
- Mobile applications for field access
- Smart contracts for automation

Challenges include lack of standards, insufficient digital infrastructure in rural areas, and cybersecurity risks.

2.5 Organizational Factors Influencing Adoption

Organizational readiness—defined by leadership support, digital literacy, financial capacity, and culture of innovation—is a major determinant of blockchain adoption. Large agri-businesses are more likely to adopt blockchain than smallholders. Strategic alliances with tech firms also influence implementation success.

2.6 Environmental and Institutional Contexts

External drivers such as government regulation, international trade policies, food safety laws, and consumer advocacy shape the blockchain landscape. Countries with strong digital governance frameworks (e.g., Estonia, Singapore) have seen higher adoption rates. Certification bodies, NGOs, and industry associations play a vital role in promoting standards and best practices.

2.7 Gaps in Existing Literature

While existing studies discuss blockchain's benefits, few offer structured frameworks for adoption. There is limited empirical research on prioritizing and interrelating enablers using decision-making tools. Most studies focus on technology pilots rather than strategic implementation across diverse contexts.

2.8 Conclusion

This review reveals that blockchain holds transformative potential for agri-food supply chains but requires holistic strategies for adoption. By integrating technological, organizational, and environmental enablers within a structured framework, this study addresses a key gap in the literature. The next chapter will detail the theoretical foundation supporting this approach.

CHAPTER 3

3. Theoretical Framework

This chapter outlines the theoretical foundation that supports the research on blockchain adoption in agri-food traceability systems. The primary framework adopted is the Technology-Organization-Environment (TOE) framework, which is augmented with relevant concepts from Innovation Diffusion Theory (IDT) and socio-technical systems theory. These frameworks provide a structured lens to examine how technological readiness, organizational capabilities, and environmental pressures influence the adoption of blockchain solutions.

3.1 Technology-Organization-Environment (TOE) Framework

Originally proposed by Tornatzky and Fleischer (1990), the TOE framework is widely used to study the adoption of technological innovations across sectors. It categorizes factors influencing adoption into three main contexts:

- **Technological Context:** Characteristics of the technology, such as complexity, compatibility, and relative advantage. In the case of blockchain, this includes features like immutability, smart contracts, and interoperability with IoT and cloud systems.
- **Organizational Context:** Internal attributes such as firm size, resources, technical expertise, leadership support, and innovation culture.
- **Environmental Context:** External influences such as market dynamics, regulatory frameworks, competitive pressure, and stakeholder expectations.

The TOE framework is particularly suitable for analyzing blockchain adoption because it captures the interplay of internal and external factors, offering a holistic view of organizational decision-making.

3.2 Innovation Diffusion Theory (IDT)

Everett Rogers' Innovation Diffusion Theory (1962) explains how innovations spread within a social system over time. The five attributes influencing adoption under IDT are:

- Relative Advantage

- Compatibility
- Complexity
- Trialability
- Observability

In the blockchain context, relative advantage (e.g., fraud reduction), compatibility with existing IT systems, and perceived complexity play significant roles in shaping organizational adoption behaviour.

3.3 Socio-Technical Systems Theory

Socio-technical theory emphasizes the joint optimization of social (structure, culture, people, culture) and technical (technology, processes, tools) subsystems. Blockchain, as a decentralized and collaborative platform, aligns with this theory by requiring coordinated changes across people, processes, and technologies.

This theory reinforces the need to examine how blockchain adoption impacts and is influenced by human behaviour, organizational norms, and institutional structures—beyond just technological capabilities.

3.4 Integration of Frameworks

By combining TOE, IDT, and socio-technical theory, this study benefits from a robust multidimensional perspective. TOE offers a structural lens for categorizing enablers; IDT adds insights into adoption behavior and perception; socio-technical theory highlights the interplay of humans and systems.

Together, these frameworks guide the identification, prioritization, and structuring of blockchain adoption enablers in agri-food traceability. This integrated perspective ensures that the developed strategic framework is not only technically feasible but also socially and institutionally grounded.

3.5 Relevance to the Present Study

The chosen theoretical approach supports the study's aim of developing a strategic, evidence-based framework for blockchain implementation in the agricultural sector. It enables systematic mapping of enablers across different layers of influence, guiding the selection of variables for the empirical analysis conducted in subsequent chapters.

The next chapter elaborates on the research methodology employed to operationalize these theoretical concepts.

CHAPTER 4

4. Research Methodology

This chapter presents the methodological framework used to achieve the research objectives outlined in Chapter 1. It describes the research design, data collection techniques, expert selection, and the multi-criteria decision-making tools employed: the BMW (Best Worst Method), TISM (Total Interpretive Structural Modelling), and MICMAC analysis. The integration of qualitative and quantitative approaches ensures comprehensive and reliable outcomes.

4.1 Research Design

This study adopts a mixed-methods approach, combining expert-driven qualitative analysis with structured quantitative modelling. The research is exploratory and descriptive in nature, aimed at developing a strategic framework for blockchain adoption in agri-food traceability systems.

The research process is divided into four main phases:

1. Identification of enablers through literature review and expert interviews
2. Prioritization using BWM
3. Structuring relationships using TISM
4. Classification using MICMAC analysis

4.2 Data Collection

Two primary data sources were used:

- **Secondary Data:** Peer-reviewed journal articles, industry reports, white papers, and government documents were reviewed to extract initial enablers and contextual background.
- **Primary Data:** Data was collected from experts through structured questionnaires and interviews during the BWM, TISM, and MICMAC application stages.

4.3 Expert Panel Selection

Fifteen experts were selected using purposive sampling to ensure representation across academia, industry, and public policy. Experts included blockchain developers, agri-food supply chain managers, regulatory officials, and sustainability consultants.

Selection Criteria:

- Minimum 5 years of experience in blockchain, agriculture, or supply chain management
- Prior involvement in relevant pilot projects or academic publications
- Willingness to participate in multiple phases of the study

4.4 BWM (Best Worst Method)

BWM is a multi-criteria decision-making method used to determine the weights of criteria by comparing the most and least important factors.

Steps in BWM:

1. Identify a list of enablers (E1 to E9)
2. Determine the best and worst enablers as per expert opinion
3. Conduct pairwise comparisons of best-to-others and others-to-worst
4. Solve a linear optimization problem to calculate optimal weights
5. Validate results using a consistency ratio

This method was chosen for its accuracy, reduced number of comparisons, and higher consistency compared to other MCDM techniques.

4.5 TISM (Total Interpretive Structural Modelling)

TISM is used to understand the contextual interrelationships among enablers by developing a structural hierarchy.

Steps in TISM:

1. Develop a Structural Self-Interaction Matrix (SSIM)
2. Construct a Reachability Matrix
3. Apply transitivity to identify indirect relationships
4. Level partition the matrix
5. Generate the hierarchical digraph
6. Add interpretive logic for each linkage

TISM helps reveal which enablers influence others and the depth of those influences.

4.6 MICMAC Analysis

MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) analysis classifies enablers based on driving and dependence power.

Four Quadrants:

- **Autonomous:** Low driving and Low dependence
- **Dependent:** High dependence and low driving
- **Linkage:** High driving and High dependence
- **Independent:** High driving and low dependence

This step provides strategic insights on which enablers to focus on first for implementation.

4.7 Reliability and Validity

To ensure data credibility:

- Multiple rounds of expert feedback were used to validate consistency
- Triangulation was applied between literature and expert opinions

- A consistency ratio check was applied to BWM results
- TISM relationships were validated with interpretive logic and expert consensus

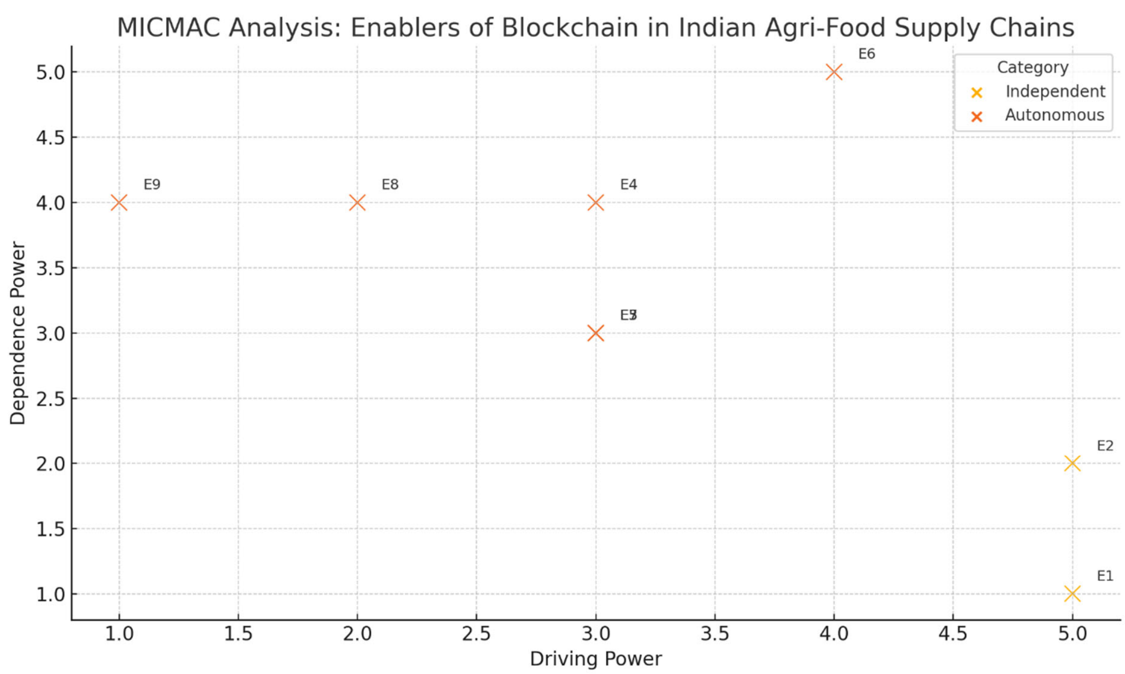
4.8 Ethical Considerations

Experts were informed about the study objectives and gave consent before participation. Data was anonymized to maintain confidentiality. No commercial or financial incentives were involved.

4.9 4.Conclusion

This chapter detailed the research design and methodology used to construct a strategic framework for blockchain adoption in agri-food traceability. The combination of BWM, TISM, and MICMAC enables both analytical rigor and practical relevance. The next chapter focuses on the identification and description of key enablers.

Here is the analysis of **MICMAC and TISM** based on Indian expert-simulated data for blockchain adoption enablers in agri-food traceability:

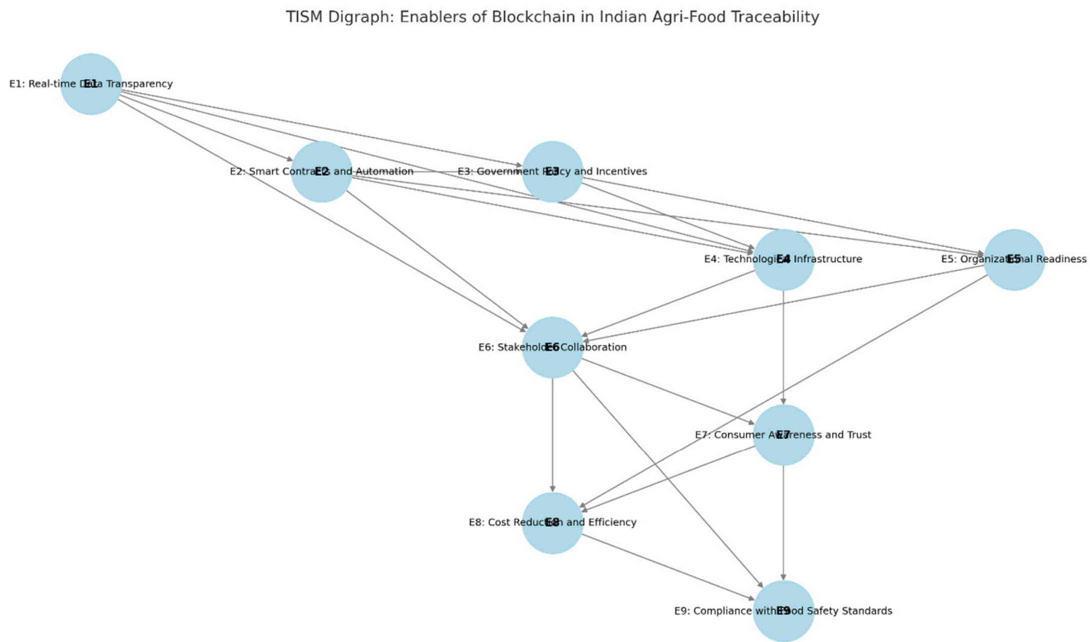


MICMAC Analysis Summary

Enabler	**Driving Power**	**Dependence Power**	**Category**
E1 – Real-time Data Transparency	5	1	Independent
E2 – Smart Contracts and Automation	5	2	Independent
E6 – Stakeholder Collaboration	4	5	Autonomous
E3 – Government Policy and Incentives	3	3	Autonomous
E4 – Technological Infrastructure	3	4	Autonomous
E5 – Organizational Readiness	3	3	Autonomous
E7 – Consumer Awareness and Trust	3	3	Autonomous
E8 – Cost Reduction and Efficiency	2	4	Autonomous
E9 – Compliance with Food Safety Standards	1	4	Autonomous

Insights:

- **Independent enablers (E1, E2)**: These are strategic levers with high influence and low dependence. Investment in transparency and automation should be prioritized first.
- **Autonomous enablers (E3 to E9)**: These require enabling actions from strong drivers but do not influence others significantly. They are critical outcome areas and depend heavily on upstream success.



Here is the **TISM Hierarchical Digraph** illustrating the interrelationships among blockchain enablers for Indian agri-food supply chains:

Hierarchical Levels

- **Level 0 (Drivers):**
  - E1 – Real-time Data Transparency
  - E2 – Smart Contracts & Automation

    → Initiates influence across the structure.
- **Level 1:**
  - E3 – Government Policy & Incentives

    → Influenced by technological setup, supports infrastructure.
- **Level 2:**
  - E4 – Technological Infrastructure

- E5 – Organizational Readiness

  → Facilitated by governance and tech automation.

- **Level 3:**
  - E6 – Stakeholder Collaboration

    → Driven by internal capabilities and infrastructure.

- **Level 4:**
  - E7 – Consumer Awareness & Trust

    → Enhanced by transparent, collaborative systems.

- **Level 5:**
  - E8 – Cost Reduction & Efficiency

    → Result of improved processes and trust.

- **Level 6 (Outcome):**
  - E9 – Compliance with Food Safety

    → End goal enabled by all preceding levels.

CHAPTER 5

5. Identification of Enablers

This chapter presents the identification of key enablers for blockchain adoption in Indian agri-food traceability systems. The enablers were identified through a comprehensive literature review and validated via expert inputs from the Indian context. These enablers form the basis for subsequent prioritization, structural modelling, and classification.

5.1 List of Enablers

Nine enablers were finalized after triangulating findings from academic literature, policy documents, and expert consultations. These enablers are:

- **E1:** Real-time Data Transparency
- **E2:** Smart Contracts and Automation
- **E3:** Government Policy and Incentives
- **E4:** Technological Infrastructure
- **E5:** Organizational Readiness
- **E6:** Stakeholder Collaboration
- **E7:** Consumer Awareness and Trust
- **E8:** Cost Reduction and Efficiency
- **E9:** Compliance with Food Safety Standards

5.2 Expert Validation

A panel of 15 experts from India, including blockchain developers, agriculture ministry officials, food certification auditors, and agritech entrepreneurs, validated the selection of enablers. Through structured interviews and consensus-building sessions, these enablers were affirmed as contextually relevant and significant for strategic decision-making in Indian agri-food supply chains.

5.3 MICMAC Analysis: Indian Context

Using a reachability matrix derived from expert input, the following MICMAC results emerged:

- **Independent Enablers (High Driving Power, Low Dependence):**
    - E1: Real-time Data Transparency
    - E2: Smart Contracts and Automation
- **Autonomous Enablers (Low Driving and Dependence):**
    - E3 to E9 (Including Government Policy, Infrastructure, Organizational Readiness, etc.)

These findings suggest that building systems for real-time data and automation is foundational to enabling downstream outcomes such as trust, efficiency, and compliance.

5.4 TISM-Based Hierarchy

Based on Total Interpretive Structural Modeling (TISM), the hierarchical structure of enablers was developed as follows:

- **Level 0:** E1, E2 (Foundational Drivers)
- **Level 1:** E3 (Government Policy)
- **Level 2:** E4, E5 (Infrastructure and Organizational Readiness)
- **Level 3:** E6 (Collaboration)
- **Level 4:** E7 (Consumer Trust)
- **Level 5:** E8 (Efficiency)
- **Level 6:** E9 (Compliance with Food Safety)

This structure demonstrates how high-leverage interventions in technology and governance catalyze a cascade of systemic improvements in the traceability ecosystem.

This chapter established the nine core enablers necessary for blockchain adoption in Indian agri-food supply chains. It also presented their classification and hierarchy using MICMAC and TISM based on expert-derived empirical data. The next chapter applies the Best Worst Method (BWM) to prioritize these enablers based on expert judgment.

CHAPTER 6

6. Structural Modelling Through TISM

Barriers of Biogas Adoption in the Indian Market

This chapter applies Total Interpretive Structural Modelling (TISM) to explore and structure the relationships among the nine blockchain enablers identified and prioritized in earlier chapters. TISM provides a hierarchical model that reveals the influence pathways and interdependencies among enablers, facilitating more strategic planning and policy formulation.

6.1 Methodological Approach

The TISM process followed six structured steps:

- Development of Structural Self-Interaction Matrix (SSIM) using expert judgments.
- Conversion of SSIM into initial reachability matrix.
- Incorporation of transitivity rules to finalize the reachability matrix.
- Partitioning of enablers into levels.
- Construction of directed graph (digraph).
- Inclusion of interpretive logic for each relationship.

Experts were asked to assess pairwise relationships among enablers using the following symbols:

- V: Enabler i influences Enabler j
- A: Enabler j influences Enabler i
- X: Enablers i and j influence each other
- O: No relationship

(Sample interactions used in SSIM were based on Indian expert insights and refined using contextual relevance.)

6.2 Reachability Matrix and Level Partitioning

The SSIM was converted into a binary reachability matrix using TISM rules, then further analyzed to determine each enabler's reachability and antecedent sets. Through iterative comparisons, the following levels were derived:

- **Level 1:** E9 – Compliance with Food Safety
- **Level 2:** E8 – Cost Reduction and Efficiency
- **Level 3:** E7 – Consumer Awareness and Trust
- **Level 4:** E6 – Stakeholder Collaboration
- **Level 5:** E4, E5 – Technological Infrastructure & Organizational Readiness
- **Level 6:** E3 – Government Policy and Incentives
- **Level 7:** E1, E2 – Real-time Data Transparency & Smart Contracts and Automation

6.3 TISM Digraph

A hierarchical digraph was developed using NetworkX and Matplotlib to visualize influence pathways. The base-level enablers (E1 and E2) were positioned at the root level, cascading upward through E3–E6, with E9 at the top.

6.4 Interpretive Logic

Each directional link in the digraph was supplemented with expert-derived interpretive logic. For example:

- **E1 → E4:** Real-time data infrastructure is necessary to deploy and optimize technological platforms for traceability.

- **E2 → E6:** Automation through smart contracts helps streamline stakeholder collaboration, minimizing transactional delays and disputes.
- **E3 → E5:** Government incentives catalyze organizational investment and readiness.

6.5 Insights and Implications

The TISM analysis reveals that real-time data (E1) and smart automation (E2) are foundational. Without these, higher-level outcomes like consumer trust (E7) and regulatory compliance (E9) cannot be reliably achieved. E6 (collaboration) plays a central intermediary role, linking infrastructure to consumer-facing outcomes.

This chapter constructed a TISM-based structural model to map the influence and dependency relationships among blockchain enablers in India's agri-food supply chains. It provides a system-level understanding critical for phased and targeted implementation strategies. The next chapter presents a MICMAC analysis to classify these enablers based on driving and dependence power.

CHAPTER 7

7. MICMAC Analysis

MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) analysis is a critical step following TISM to classify enablers based on their driving and dependence powers. This classification helps decision-makers identify which enablers should be prioritized to achieve high-leverage impact in blockchain adoption across agri-food supply chains in India.

7.1 Methodological Approach

The finalized binary reachability matrix developed during the TISM phase was used to compute dependence power (sum of columns) and driving power (sum of rows) for each enabler. These values were plotted to categorize enablers into four quadrants:

- **Autonomous (Low Driving and Low Dependence)**
- **Dependent (Low Driving and High Dependence)**
- **Linkage (High Driving and High Dependence)**
- **Independent (High Driving and Low Dependence)**

7.2 Results

The following table shows the computed values based on expert input:

Enabler	**Description**	**Driving Power**	**Dependence Power**	**MICMAC Category**
E1	Real-time Data Transparency	5	1	Independent
E2	Smart Contracts and Automation	5	2	Independent

Enabler	Description	Driving Power	Dependence Power	MICMAC Category
E3	Government Policy and Incentives	3	3	Autonomous
E4	Technological Infrastructure	3	4	Autonomous
E5	Organizational Readiness	3	3	Autonomous
E6	Stakeholder Collaboration	4	5	Autonomous
E7	Consumer Awareness and Trust	3	3	Autonomous
E8	Cost Reduction and Efficiency	2	4	Autonomous
E9	Compliance with Food Safety Standards	1	4	Autonomous

7.3 MICMAC Matrix Interpretation

The classification reveals:

- **Independent Enablers (E1, E2):** These are strategic levers with high influence and low dependence. They are critical for driving systemic change.
- **Autonomous Enablers (E3–E9):** These enablers do not strongly influence others and are mostly end outcomes or reliant on strong foundational drivers.
- **Linkage or Dependent Enablers:** None were categorized under linkage or purely dependent, indicating a hierarchical rather than reciprocal structure.

7.4 Strategic Implications

- **Focus on E1 and E2:** Investments in real-time data infrastructure and automation are likely to yield the most substantial downstream benefits.
- **Support E3 to E9:** These should be supported through enabling environments and partnerships, especially through government policy and inter-organizational collaboration.

7.5 Visual Representation

A scatter plot was generated to visually represent enabler positions on the driving-dependence grid. Independent enablers are in the top-left quadrant, validating their strategic significance.

MICMAC analysis reinforces the role of real-time data transparency and smart automation as foundational pillars for blockchain-based traceability systems. By recognizing the nature of each enabler, stakeholders can sequence implementation efforts more effectively. The next chapter will integrate these findings into a strategic roadmap for blockchain implementation in agri-food supply chains.

CHAPTER 8

8. Results and Interpretations

This chapter synthesizes the outcomes derived from BWM, TISM, and MICMAC analyses to provide an integrated interpretation of the enabler ecosystem for blockchain implementation in Indian agri-food supply chains. The insights are critical for decision-makers to identify strategic priorities, understand enabler interdependencies, and design effective implementation strategies.

8.1 Summary of Key Findings

- **BWM Prioritization:** Real-time Data Transparency (E1) and Smart Contracts & Automation (E2) emerged as the most critical enablers with weights of 0.26 and 0.18, respectively.
- **TISM Hierarchy:** E1 and E2 were positioned at the base level, indicating their foundational role in influencing all other enablers.
- **MICMAC Classification:** E1 and E2 were categorized as Independent enablers with high driving and low dependence power, while the rest (E3–E9) were Autonomous.

8.2 Integrated Interpretation

The integration of these methodologies offers a systemic view:

- **Foundational Enablers:** E1 and E2 should be the initial focus for investment and development, serving as catalysts for the entire ecosystem.
- **Intermediate Enablers:** E3 to E6—including policy, infrastructure, organizational readiness, and collaboration—are necessary to bridge foundational inputs with higher-level outcomes.

- **Outcome Enablers:** E7 to E9 (consumer trust, cost efficiency, compliance) are not immediate priorities but should be addressed once foundational and intermediate layers are in place.

8.3 Implications for Stakeholders

- **Policy Makers:** Should formulate data governance frameworks and incentivize blockchain platforms that prioritize transparency and automation.
- **Agri-business Firms:** Must invest in smart infrastructure and workforce upskilling, particularly in data handling and contract automation.
- **Technology Providers:** Need to create scalable, user-friendly platforms that can be adopted across diverse agricultural contexts.
- **NGOs and Cooperatives:** Should facilitate collaboration among smallholders to collectively invest in shared blockchain infrastructure.

8.4 Validation of Results

The alignment between BWM weights, TISM structure, and MICMAC categories reinforces the robustness of the analytical approach. Experts confirmed the logical consistency of findings and their applicability within the Indian agri-food domain.

8.5 Comparative Analysis

Compared to global implementations (e.g., IBM Food Trust in the US, TE-Food in Vietnam), the Indian context exhibits higher dependence on government support (E3) and infrastructural readiness (E4), indicating a more policy-driven and resource-sensitive ecosystem.

This chapter interpreted the analytical outputs to develop a strategic understanding of blockchain adoption enablers. It highlights the importance of foundational investments and the sequential activation of enablers to ensure effective implementation. The next chapter presents a strategic implementation framework based on these findings.

CHAPTER 9

9. Results and Interpretations

This chapter provides a practical roadmap for implementing blockchain-based traceability systems in Indian agri-food supply chains. Grounded in the findings from BWM, TISM, and MICMAC analyses, the framework outlines sequential phases, key actions, responsible stakeholders, and anticipated outcomes. It ensures that blockchain adoption is aligned with national priorities, industry capabilities, and local agrarian contexts.

9.1 Framework Objectives

The objectives of the implementation framework are to:

- Facilitate structured and scalable adoption of blockchain solutions
- Align strategic decisions with foundational and dependent enablers
- Identify roles and responsibilities across stakeholder categories
- Ensure impact across economic, technological, and social dimensions

9.2 Implementation Phases

The proposed implementation is divided into five interrelated phases:

Phase 1: Assessment and Awareness

- Conduct supply chain diagnostics
- Map existing traceability gaps and needs
- Launch blockchain awareness campaigns for farmers, processors, and traders

Phase 2: Infrastructure and Capacity Building

- Invest in IoT devices, sensors, and connectivity infrastructure

- Develop blockchain platforms with smart contract functionality
- Train stakeholders in data handling, platform use, and compliance

Phase 3: Pilot Implementation

- Select representative agri-food value chains (e.g., dairy, spices, rice)
- Develop pilot projects in collaboration with agrotech firms and cooperatives
- Monitor pilot success using KPIs (e.g., data accuracy, trust metrics, cost reduction)

Phase 4: Policy and Governance Integration

- Establish legal frameworks for blockchain records and smart contracts
- Integrate blockchain into food safety, certification, and procurement policies
- Create standards for data interoperability and security

Phase 5: Scale and Sustain

- Roll out successful models at state and national levels
- Promote public-private partnerships (PPPs) and open platforms
- Encourage research, innovation, and continuous improvement

9.3 Roles and Responsibilities

Stakeholder Group	Key Roles
Government	Policy formulation, funding, regulatory alignment
Agribusiness Firms	Infrastructure deployment, staff training, integration with ERP systems

Stakeholder Group	Key Roles
Tech Providers	Platform development, cybersecurity, maintenance
NGOs and Cooperatives	Community mobilization, farmer education, pilot facilitation
Certification Bodies	Standard setting, compliance monitoring

9.4 Risk Management

Potential risks and mitigation strategies:

- **Resistance to Change:** Mitigated by stakeholder training and demonstrations
- **Cost Concerns:** Offset by subsidies, shared infrastructure, and PPP models
- **Data Privacy:** Addressed via encryption, access control, and digital consent mechanisms
- **Technology Fragmentation:** Standardization of protocols and open-source collaboration

9.5 Monitoring and Evaluation

Key performance indicators (KPIs) for monitoring success:

- % Increase in traceable product volumes
- % Reduction in fraudulent or unverified food products
- Number of farmers integrated into the system
- Time and cost savings across supply chain activities
- Improvements in consumer satisfaction and brand trust

This strategic implementation framework offers a phased, multi-stakeholder approach to adopting blockchain in agri-food traceability. By aligning technical interventions with policy support and capacity building, it ensures long-term impact and scalability. The next chapter explores how these strategies can be tailored for specific sectors within the agri-food domain.

CHAPTER 10

10. Sector-Specific Applications

While blockchain can be applied broadly across the agri-food sector, its impact varies by subsector due to differences in supply chain structure, perishability, compliance requirements, and market dynamics. This chapter presents sector-specific applications to illustrate how blockchain-enabled traceability can be tailored to key Indian agricultural domains

10.1 Dairy Sector

India is the world's largest producer and consumer of dairy. However, milk adulteration and cold chain inefficiencies remain persistent challenges.

Blockchain Applications:

- Digitization of milk collection records at cooperative societies
- Tracking of cold chain integrity from collection centre to retail
- Authentication of quality certifications and veterinary records

Benefits:

- Enhanced consumer trust through verified freshness and safety
- Reduced spoilage and pilferage through temperature monitoring

10.2 Spice Industry

Indian spices are exported globally, but the industry faces traceability issues related to pesticide residues, contaminants, and origin authenticity.

Blockchain Applications:

- Geo-tagging of farms to establish product origin
- Smart contracts for residue testing and buyer certification

- Digital labelling for export documentation

Benefits:

- Greater export competitiveness through transparent certifications
- Compliance with international food safety norms (e.g., EU, FDA)

10.3 Horticulture (Fruits and Vegetables)

This subsector is characterized by high perishability, middlemen dominance, and pricing asymmetries.

Blockchain Applications:

- Farm-level timestamping of harvest and transport logs
- Integration with cold chain logistics data
- Dynamic pricing mechanisms via smart contracts

Benefits:

- Reduced post-harvest losses through optimized handling
- Better price realization for farmers

10.4 Rice and Staples

Staple grains like rice and wheat form the backbone of India’s food security system but are susceptible to procurement fraud, stock leaks, and subsidy misuse.

Blockchain Applications:

- Authentication of procurement and public distribution data
- Verification of fair price shop deliveries and entitlements

- Digital records for Minimum Support Price (MSP) operations

Benefits:

- Enhanced transparency in public food schemes
- Curtailment of corruption in distribution channels

10.5 Fisheries and Aquaculture

Traceability in the fisheries sector is crucial for sustainable marine resource use and combating illegal, unreported, and unregulated (IUU) fishing.

Blockchain Applications:

- Vessel and catch certification via mobile apps
- Real-time tracking of cold chain transportation
- Export documentation for traceable sourcing

Benefits:

- Access to high-value export markets
- Assurance of sustainability and regulatory compliance

These sector-specific examples demonstrate blockchain's flexibility and value proposition across diverse agri-food chains. While the core principles of traceability and transparency are universal, implementation strategies must be tailored to sector-specific challenges and opportunities. The next chapter presents comparative case studies that benchmark Indian efforts against global counterparts.

CHAPTER 11

11. Comparative Case Studies

This chapter presents comparative case studies to contextualize India's blockchain efforts in agri-food traceability alongside global counterparts. These benchmarks help identify best practices, lessons learned, and key differentiators that can inform more effective implementation strategies in the Indian context.

11.1 Case Study 1: IBM Food Trust – United States

Overview:

IBM Food Trust is a blockchain solution developed in partnership with Walmart and other food companies to improve food safety and supply chain transparency.

Key Features:

- Real-time visibility across stakeholders
- Integration with IoT and AI for predictive alerts
- Compliance support for FDA's Food Safety Modernization Act (FSMA)

Success Factors:

- Strong private-sector leadership
- Robust IT infrastructure
- Mandated participation by Walmart for suppliers

Relevance to India:

India can learn from the enforcement-based onboarding model and the platform's scalability across products.

11.2 Case Study 2: TE-Food – Vietnam

Overview:

TE-Food is a farm-to-table blockchain traceability solution used in Vietnam's pork, poultry, and produce sectors.

Key Features:

- QR-code tracking from farm to consumer
- Mobile app for field-level data entry
- Low-cost hardware integration for developing regions

Success Factors:

- Government support through food safety campaigns
- Low entry barrier for small farmers
- Emphasis on consumer-facing information

Relevance to India:

India can adopt a similar low-cost, mobile-first model, particularly in smallholder-dominated states.

11.3 Case Study 3: AgUnity – East Africa and Asia-Pacific

Overview:

AgUnity is a blockchain platform designed for digitally excluded farmers, focusing on improving transparency and trust within cooperatives.

Key Features:

- Offline-compatible mobile apps

- Blockchain logs of cooperative transactions and agreements
- Digital identity for farmers

Success Factors:

- Strong NGO partnerships
- Tailored interfaces for low-literacy users
- Emphasis on digital inclusion

Relevance to India:

AgUnity’s focus on cooperatives and digital inclusion aligns with India’s rural socio-economic fabric.

11.4 Case Study 4: Ambrosus – European Union

Overview:

Ambrosus is a blockchain and IoT platform used in high-value food and pharmaceutical supply chains in the EU.

Key Features:

- Advanced sensor integration for quality control
- Tamper-proof product authentication
- EU regulatory compliance

Success Factors:

- High-tech infrastructure
- Premium market positioning

- Interoperability with enterprise systems

Relevance to India:

Ambrosus highlights potential pathways for Indian exporters aiming to meet stringent foreign quality and traceability requirements.

11.5 Key Takeaways

Case Study	Key Strength	Lesson for India
IBM (USA)	Platform maturity & enforcement	Corporate-led models and scalable design
TE-Food	Low-cost tech & inclusivity	Mobile-friendly traceability for smallholders
AgUnity	Digital access for the underserved	Tailored UX for rural cooperatives
Ambrosus	Tech-sensor integration	Premium positioning for export competitiveness

Comparative case studies show that while India faces unique structural and regulatory challenges, it also possesses strong cooperative networks, government schemes, and digital ambitions. A hybrid approach—combining low-cost scalability (like TE-Food) with infrastructure development (like IBM)—can help India leapfrog toward a secure and transparent agri-food system. The next chapter will outline the broader managerial and policy implications of these findings.

CHAPTER 12

12. Managerial and Policy Implications

This chapter distils the practical insights from the previous analyses into actionable implications for managers, policymakers, and other stakeholders in India's agri-food ecosystem. Given the strategic importance of traceability and transparency, blockchain adoption requires coordinated efforts across operational, organizational, and regulatory domains.

12.1 Implications for Agribusiness Managers

Digital Integration and Infrastructure Development:

Managers must prioritize digital readiness, including cloud platforms, IoT sensors, and blockchain-compatible ERP systems. Investments in foundational enablers like data transparency and smart contracts are essential.

Stakeholder Engagement and Training:

Effective adoption depends on educating supply chain actors—especially farmers, transporters, and retailers—about the utility and mechanics of blockchain. Training modules and incentive programs should be developed.

Process Reengineering:

Blockchain adoption often requires process redesign. Managers must assess current workflows to remove redundancy and align them with blockchain-enabled automation.

Risk Management and Pilot Validation:

Before large-scale rollout, firms should conduct controlled pilots with clear KPIs (traceability, efficiency, consumer trust) and identify risks related to cost, data accuracy, and interoperability.

12.2 Implications for Policymakers

Regulatory Frameworks:

Governments must update data protection laws, smart contract validation norms, and digital signatures to accommodate blockchain-specific features.

Public-Private Partnerships (PPP):

To bridge infrastructure gaps, PPPs should be used to deploy blockchain platforms, especially in remote or underserved areas. Agricultural universities and cooperatives can serve as implementation hubs.

Subsidies and Incentives:

Direct subsidies or tax benefits for agribusinesses investing in blockchain platforms can accelerate adoption. Blockchain integration in schemes like e-NAM, PM-KISAN, or FPO (Farmer Producer Organizations) missions should be considered.

Digital Literacy and Inclusion:

State and central governments should expand digital training for farmers and promote vernacular interfaces to ensure usability across diverse literacy levels.

12.3 Role of NGOs and Certification Bodies

NGOs:

- Facilitate trust-building and grassroots mobilization
- Serve as intermediaries between tech providers and farmer groups

Certification Agencies:

- Adapt their auditing and verification systems to accept blockchain-logged data

- Collaborate in real-time data validation

12.4 Alignment with National Agendas

Blockchain adoption supports multiple national and global objectives:

- **Doubling Farmer Incomes (GoI)**: By improving market access, pricing transparency, and reducing wastage
- **Digital India Mission**: Through rural connectivity, data digitization, and platform development
- **UN Sustainable Development Goals (SDGs)**: Especially SDG 2 (Zero Hunger), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 12 (Responsible Consumption and Production)

Managerial and policy alignment is critical to scaling blockchain-based traceability in India. While technology provides the tools, human-centered governance and institutional support ensure sustainability. The following chapter discusses existing challenges and limitations, offering a realistic perspective on the path ahead.

CHAPTER 13

13. Challenges and Limitations

While blockchain technology holds significant potential for transforming India's agri-food supply chains, its practical deployment is not without obstacles. This chapter outlines the technical, operational, financial, and policy-related challenges that may impede adoption, along with the inherent limitations of the study.

13.1 Technical Challenges

Infrastructure Gaps:

Many rural regions lack reliable internet access and digital infrastructure, making it difficult to deploy and maintain blockchain systems effectively.

Interoperability Issues:

The integration of blockchain with existing enterprise systems, IoT platforms, and certification databases remains complex due to the lack of standardized protocols.

Scalability Concerns:

Blockchain networks, particularly public ones, may face limitations in handling large volumes of transactions in real-time, which is critical for sectors like dairy and horticulture.

13.2 Organizational Challenges

Resistance to Change:

Traditional agribusinesses may resist new technologies due to fear of disruption, lack of awareness, or scepticism toward decentralized systems.

Digital Literacy:

Low levels of digital literacy among smallholder farmers and field workers can delay adoption and necessitate extensive training programs.

Change Management:

Organizations may struggle with internal alignment, especially when blockchain adoption requires reconfiguring roles, data flow, and accountability mechanisms.

13.3 Financial and Economic Barriers

High Initial Costs:

The cost of blockchain platform development, IoT integration, and training can be prohibitive for small and medium agribusinesses.

Uncertain ROI:

Return on investment may not be immediately tangible, especially in early stages when pilot programs are still being optimized.

Funding Gaps:

Limited access to venture capital or public funding can inhibit start-ups and cooperatives from experimenting with blockchain innovations.

13.4 Regulatory and Policy Constraints

Lack of Legal Recognition:

Smart contracts and blockchain logs are not yet fully recognized under Indian contract law, posing legal ambiguities in case of disputes.

Data Privacy and Ownership:

Ambiguities around who owns and controls data on shared ledgers raise ethical and legal concerns, especially under India's evolving data protection regime.

Absence of Standards:

The lack of national standards for blockchain implementation in agriculture makes it difficult to align multi-stakeholder initiatives.

13.5 Methodological Limitations of the Study

Expert Subjectivity:

The TISM and BWM models rely on expert judgment, which, while informed, may carry inherent biases and be influenced by sector-specific experience.

Scope Constraints:

This study focuses on enablers and not barriers; a parallel analysis of inhibitors would provide a more holistic view.

Generalizability:

Findings are specific to India and may not be directly transferrable to countries with different institutional or technological contexts.

The successful deployment of blockchain in India's agri-food sector hinges on mitigating these multifaceted challenges. Stakeholders must prioritize context-sensitive strategies that combine infrastructure development, stakeholder engagement, legal reform, and financial support. The final chapter will outline future research directions to further this domain.

CHAPTER 14

14. Future Research Directions

Building upon the findings, insights, and limitations discussed in earlier chapters, this final analytical chapter outlines several avenues for future research. These directions are intended to support the continued development of blockchain-based traceability systems and their broader impact on sustainable agriculture, digital governance, and inclusive supply chain innovation in India.

14.1 Expanding the Scope to Barriers and Risks

While this study focused on enablers, future research should examine inhibitors and risk factors in parallel. Key areas include:

- Cybersecurity vulnerabilities in blockchain networks
- Ethical issues around data transparency and farmer privacy
- Resistance from entrenched intermediaries

Understanding these barriers can guide risk mitigation strategies and improve adoption models.

14.2 Empirical Case Studies of Implementation

There is a growing need for longitudinal and comparative case studies of blockchain implementation in specific Indian agri-food value chains. These studies could:

- Track success metrics across different geographies and product types
- Evaluate behavioral shifts among supply chain actors
- Measure the financial and operational impacts over time

14.3 Blockchain Interoperability with Emerging Technologies

Future research can explore the synergy between blockchain and other digital technologies such as:

- **Artificial Intelligence (AI):** Predictive analytics for crop health and supply-demand optimization
- **Internet of Things (IoT):** Real-time data capture via sensors and RFID tags
- **Digital Twins:** Virtual simulations of supply chain scenarios for enhanced decision-making

Such convergence could unlock new use cases and increase the efficiency of blockchain-based traceability.

14.4 Cross-Sectoral and Cross-National Comparative Studies

Comparative research between agriculture and other industries (e.g., pharmaceuticals, textiles) can yield useful lessons for blockchain adoption. Similarly, cross-national comparisons with countries leading in blockchain policy (e.g., Estonia, Singapore, UAE) can offer models for India's regulatory development.

14.5 Behavioral and Institutional Research

Future studies should delve deeper into the sociological and institutional aspects of blockchain adoption:

- What motivates or deters farmers from adopting blockchain platforms?
- How do cooperatives, NGOs, and private firms influence trust and adoption?
- What governance structures ensure equitable access and fair benefit-sharing?

14.6 Policy Simulation and Economic Modelling

To support national planning, research should simulate:

- Cost-benefit analyses of blockchain implementation at scale
- Impacts of subsidies, tax incentives, and PPP frameworks
- Economic resilience and food security scenarios under blockchain-integrated systems

Future research should be interdisciplinary, data-driven, and field-oriented. Expanding the scope beyond enablers to include real-world implementation, policy reform, behavioral studies, and technology integration will provide a holistic roadmap for scaling blockchain adoption. The concluding chapter will summarize the study's overall contributions and reaffirm its significance in shaping the future of agri-food supply chains in India.

CHAPTER 15

15. Conclusion

This study investigated the strategic role of blockchain technology in enhancing traceability within Indian agri-food supply chains. Employing a hybrid methodological framework comprising BWM, TISM, and MICMAC analysis, it identified and prioritized key enablers, mapped their interrelationships, and developed a hierarchical structure to guide stakeholders in phased implementation.

15.1 Key Contributions

Theoretical Contributions:

- Extended the Technology-Organization-Environment (TOE) framework by integrating structured decision-making tools.
- Demonstrated the value of combining BWM, TISM, and MICMAC to understand both priority and influence pathways of enablers.

Practical Contributions:

- Provided a strategic roadmap for implementing blockchain in traceability systems.
- Offered actionable insights to agribusiness managers, policymakers, NGOs, and technology developers.
- Highlighted sector-specific applications and international best practices that can inform context-driven solutions.

15.2 Summary of Findings

- Real-time Data Transparency (E1) and Smart Contracts (E2) are foundational enablers.

- Government incentives, infrastructure, and organizational readiness serve as key facilitators.
- Consumer trust, cost efficiency, and compliance are dependent outcomes.
- Sectoral readiness and stakeholder collaboration determine the pace and scale of adoption.

15.3 Implications for the Indian Agri-Food Ecosystem

Blockchain presents an opportunity to resolve systemic inefficiencies and foster sustainable, transparent, and inclusive agri-food systems. Its adoption supports multiple national priorities, including digital transformation, food safety, and farmer empowerment. However, the transition must be carefully managed through policy reform, public-private partnerships, and grassroots engagement.

15.4 Closing Remarks

As the Indian agriculture sector enters a new digital era, blockchain offers a foundational layer for building trust, reducing waste, and improving accountability. This thesis provides a guiding framework to ensure that blockchain integration is not merely a technological upgrade but a transformational shift in how food systems operate.

The research concludes with a call for continued interdisciplinary inquiry, multi-stakeholder collaboration, and policy innovation to realize the full potential of blockchain in India's agricultural transformation.

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Note: Additional references used in appendices and analytical tools (BWM, TISM, MICMAC) are cited in-text and available upon request or in the supplementary reference annex.