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Reverse Logistics Barriers in Circular Agri-food Supply Chains: An ISM-MICMAC Approach

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ABSTRACT

Background: This study identifies and models key barriers to reverse logistics (RL) implementation in circular agri-food supply chains (AFSCs) in the Indian context and examines their interrelationships.

Methods: Fourteen barriers were identified through an extensive literature review and expert consultation. Interpretive structural modeling (ISM) was employed to develop a hierarchical structure and cross impact matrix multiplication applied to classification (MICMAC) analysis was used to classify barriers based on driving and dependence power.

Result: The findings indicate that lack of RL infrastructure (B2), high cost and low return on investment (B5) and inadequate cold chain facilities (B6) are the most influential barriers, forming the foundational layer of the system. The results highlight the need to prioritize infrastructure and financial interventions, supported by enabling policy measures for effective circular transition. The study provides a system-level understanding of barrier interrelationships and contributes to circular AFSCs literature in the Indian context.

Key words: Agri-food supply chains, Circular economy, ISM, MICMAC, Reverse logistics, Sustainability.

INTRODUCTION

The agri food supply chains (AFSCs) play a critical role in ensuring food security, economic growth and environmental sustainability across the globe (Agrawal *et al*., 2025; Dammak *et al*., 2025; Kim and Alzubi, 2024; Suryaningrat *et al*., 2026). However, the dominant linear model of production and consumption, often described as "take-make-dispose", has led to significant inefficiencies in the form of food loss, waste generation and resource depletion (Andika *et al*., 2025). In this context, the circular economy (CE) has emerged as a promising approach that focuses on resource efficiency, waste reduction and value recovery across the supply chain (Garnevska *et al*., 2026). Within the CE framework, Reverse Logistics (RL) assumes a central role. RL refers to the systematic process of collecting, transporting and processing unsold, returned, or waste products for reuse, recycling, or recovery of value (Kazancoglu *et al*., 2021). Despite its potential, the implementation of RL in AFSCs remains highly challenging, particularly in emerging economies (Shekhar *et al*., 2023). The Indian Agri food sector presents a unique and important context for examining these challenges (Banerjee *et al*., 2026; Panghal *et al*., 2023; Sonar *et al*., 2024; Swain *et al*., 2024). A careful examination of the existing literature indicates that there is limited research that systematically investigates the barriers to RL in circular AFSCs, particularly in the Indian context (Sonar *et al*., 2025). More importantly, the interrelationships among these barriers are less explored. These barriers are interconnected and influence each other in a complex manner. Some barriers act as root causes with strong driving influence, while others are dependent outcomes. Therefore, there is a need for a structured methodological approach that can capture these interdependencies and provide a holistic understanding of the system. The practical significance of this study extends beyond theoretical understanding of RL barriers. The findings can assist policymakers, agri-business firms, logistics service providers, farmer producer organizations and supply chain managers in prioritizing interventions for

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effective RL implementation. By identifying the most influential barriers and their hierarchical relationships, the study provides guidance for infrastructure development, policy formulation, investment planning, stakeholder coordination and resource allocation to facilitate the transition towards circular AFSCs in India. To address this research gap, the present study employs interpretive structural modeling (ISM) (Harefa *et al*., 2025; Surange *et al*., 2024, 2026) to develop a hierarchical structure of barriers influencing RL adoption. ISM helps in identifying the contextual relationships among barriers and organizing them into different levels based on their influence. In addition, cross impact matrix multiplication applied to classification (MICMAC) analysis is used to classify the barriers based on their driving power and dependence power.

MATERIALS AND METHODS

This study was conducted during January-March 2026 through expert consultations and structured interactions with professionals from the Maharashtra region of the Indian AFSCs sector. A systematic and structured methodology was adopted to identify, analyze and model the barriers affecting RL implementation in circular AFSCs. The methodological flow (Refer Fig 1) is aligned with established ISM procedures and follows a sequential approach starting from barrier identification to model development and classification using MICMAC.

The identified barriers are presented in Table 1. The development of the structural self interaction matrix (SSIM) is based on inputs collected from a panel of 21 experts drawn from academia, industry and AFSCs practice. The selection of experts was guided by their domain

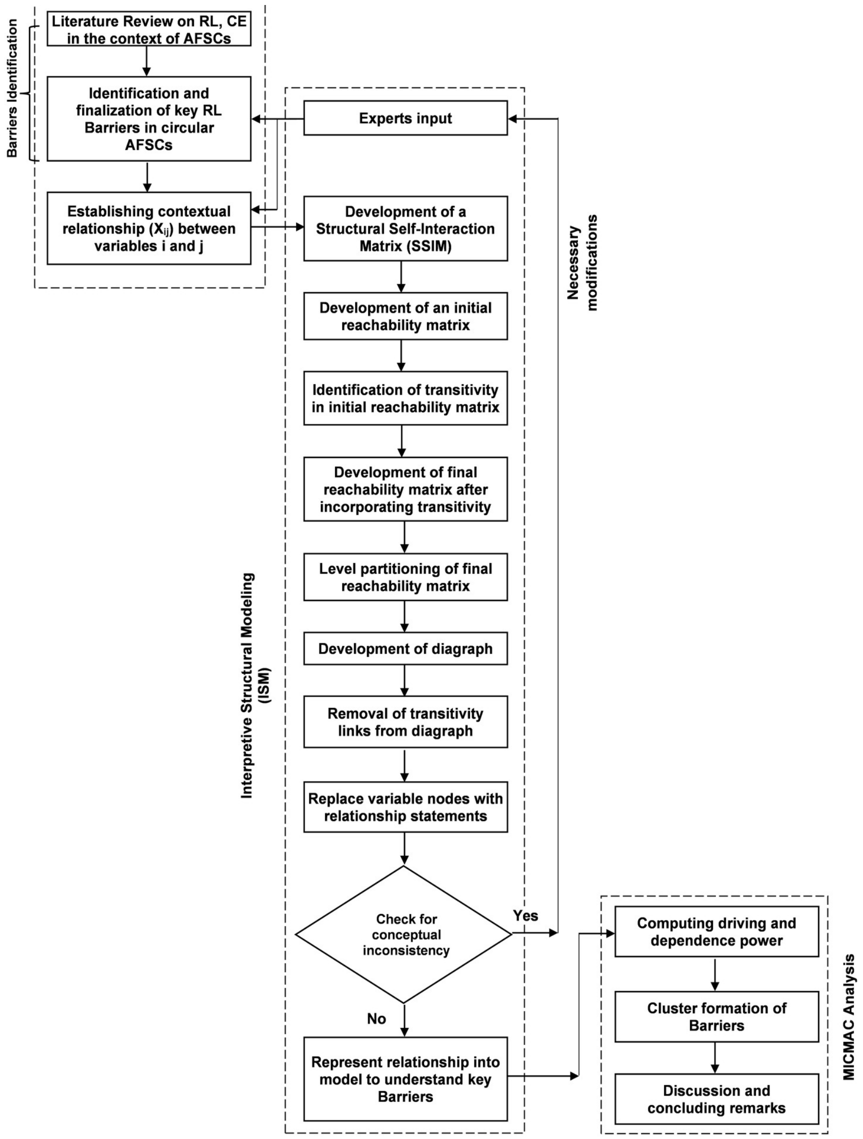

Fig 1: Methodology flow.

knowledge, professional experience and involvement in supply chain, logistics, Agri business and food processing sectors. The number of experts is considered adequate and consistent with prior ISM based studies, where panels typically range between 10 and 30 experts. A panel size of 21 ensures diversity of perspectives while maintaining manageability and consistency in responses. The profile of the experts is presented in Table 2.

The data collection was carried out in a structured manner. Initially, the list of identified barriers was shared with the experts. This was followed by individual interactions through online meetings and structured questionnaires to capture pairwise relationships among barriers. Experts were requested to indicate the direction of influence between each pair of barriers using standard ISM symbols. The iterative validation ensured reliability and consistency

Table 1: Key barriers.

Code	Barrier name	Description	Reference
B1	Fragmented smallholder production base	Highly fragmented land holdings and dispersed farmers make aggregation, collection and reverse flow management difficult.	(Shekhar *et al*., 2023)
B2	Lack of formal RL infrastructure	Absence of structured systems for collection, sorting and processing of returned or waste agri products.	(Mehmood *et al*., 2021)
B3	Absence of standardized quality grading for returns	Lack of uniform grading standards for returned or surplus produce affects recovery and redistribution efficiency.	Experts
B4	Weak traceability and data integration systems	Limited digital systems for tracking product flows reduce transparency and coordination in RL.	(Kumar *et al*., 2023)
B5	High cost and low return on investment of circular initiatives	Significant investment requirements with uncertain economic returns. discourage adoption of RL practices	(Anastasiadis *et al*., 2024)
B6	Inadequate cold chain and storage facilities	Lack of temperature-controlled storage and transportation leads to spoilage and limits recovery of perishable products.	(Singh and Jenamani, 2026)
B7	Informal and unorganized collection mechanisms	Reverse flows are managed through informal networks without standard processes, reducing efficiency.	Experts
B8	Limited awareness of circular practices among farmers	Farmers have limited knowledge about value recovery, waste utilization and circular supply chain practices.	Experts
B9	Policy gaps in agri waste and reverse flow regulations	Lack of clear policies and regulatory frameworks for waste recovery and RL.	(Kumar *et al*., 2023)
B10	Lack of incentives for waste recovery and recycling	Absence of financial or policy incentives discourages stakeholders from engaging in RL activities.	(Borrello *et al*., 2016)
B11	Poor coordination among supply chain stakeholders	Weak collaboration among farmers, processors, logistics providers and retailers hinders RL implementation.	(Jakhar and Srivastava, 2018)
B12	Cultural resistance to use of recycled or recovered products	Social perception and trust issues limit acceptance of recycled or recovered agri products.	(Mehmood *et al*., 2021)
B13	Technological constraints in waste processing and valorization	Limited access to advanced technologies for converting agri waste into value added products.	(Kumar *et al*., 2023)
B14	Market uncertainty for recovered products	Lack of stable demand and pricing for recovered products reduces economic viability.	(Govindan and Hasanagic, 2018)

Note: Barriers B3, B7 and B8 emerged during expert consultations.

in the final responses. The consolidated expert inputs were then used to develop the SSIM, which forms the basis for further ISM analysis.

Development of SSIM

The resulting SSIM is presented in Table 3. The matrix reflects the consolidated expert judgement and represents the direct relationships among the barriers considered in this study. The symbol ‘V’ represents that one barrier influences another. The symbol ‘A’ represents the reverse relationship. The symbol ‘X’ indicates mutual influence, while ‘O’ denotes no relationship.

Development of initial reachability matrix (IRM) and final reachability matrix (FRM)

Following the development of the SSIM, the next step involves converting it into the IRM, where qualitative relationships are transformed into a binary format for further analysis.

The conversion is carried out using standard ISM rules. Based on these rules, the symbols in the SSIM are replaced with binary values. For instance, where a barrier i influences barrier j, the corresponding cell takes a value of one, while the reverse cell takes a value of zero. Similarly, appropriate binary representations are assigned for other types of

Table 2: Profile of experts.

Designation	Work experience (Years)	Industry domain
Supply chain manager	18	Food processing industry
Assistant manager logistics	12	Agri iogistics and distribution
Research scholar	5	Agri supply chain research
IT manager supply chain systems	11	Agri tech and digital supply chains
Operations manager	9	Food retail and E commerce
Production engineer	7	Food processing industry
Materials manager	10	Agro based manufacturing
Maintenance engineer	6	Cold storage and warehousing
Process engineer	6	Agro processing Units
Assistant manager production	8	Packaged food industry
Production engineer	7	Dairy industry
Quality control inspector	9	Food quality and safety
Production engineer	11	Agro based consumer goods
Process engineer	7	Food packaging industry
Supply chain analyst	8	Agri logistics and cold chain
Procurement manager	13	Food procurement and sourcing
Operations executive	6	Cold chain logistics
Manager	10	Agri and food industry
Food processing coordinator	8	Farmer producer organization
Agri business manager	12	Agri input and distribution
Assistant professor-SCM	14	Higher education and research

Table 3: Structural self-interaction matrix (SSIM).

Barriers	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1
B1	A	A	O	A	A	O	A	A	A	A	O	A	O	-
B2	V	V	V	V	V	V	V	V	V	V	V	V	-	
B3	O	A	V	A	A	O	O	O	A	A	A	-		
B4	A	A	V	A	A	O	A	A	A	A	-			
B5	V	V	V	V	V	V	V	O	V	-				
B6	V	V	V	O	V	V	V	V	-					
B7	A	A	O	A	A	A	A	-						
B8	A	O	V	O	A	A	-							
B9	O	A	O	V	V	-								
B10	V	V	V	V	-									
B11	O	V	V	-										
B12	A	O	-											
B13	A	-												
B14	-													

relationships. This process results in a square matrix consisting of ones and zeros, representing direct relationships among the barriers. The IRM is presented in Table 4.

The IRM is further refined by incorporating the principle of transitivity to ensure that indirect relationships among barriers are also captured. If a barrier influences another barrier, which in turn influences a third barrier, then the first barrier is assumed to influence the third barrier indirectly. By applying transitivity, the FRM (Table 5) is obtained. This matrix reflects both direct and indirect relationships among the barriers.

Level partitioning and ISM model development

The driving power in FRM is then examined in decreasing order to understand the relative influence of barriers within the system. These values are further utilised in the level partitioning process, which forms the next stage of ISM analysis.

Level partitioning is performed to establish the hierarchical structure of barriers. For each barrier, the reachability set (R_i) consists of the barrier itself along with those it can influence, while the antecedent set (A_i) includes the barrier itself and those that influence it. The intersection set is obtained as the common elements between the reachability and antecedent sets. Barriers for which the reachability set and intersection set are identical are assigned to the top level of the hierarchy. Once identified, these barriers are removed from further iterations and the process is repeated until all levels are determined.

Based on the FRM and level partitioning results, the conical matrix (Table 6) is developed by rearranging the barriers according to their hierarchical levels. This matrix presents the driving power and dependence power of each barrier in a structured form and serves as the basis for developing the ISM digraph.

The ISM digraph (Fig 2) is developed based on the conical matrix to visually represent the interrelationships

Table 4: IRM.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
B2	0	1	1	1	1	1	1	1	1	1	1	1	1	1
B3	1	0	1	0	0	0	0	0	0	0	0	1	0	0
B4	0	0	1	1	0	0	0	0	0	0	0	1	0	0
B5	1	0	1	1	1	1	0	1	1	1	1	1	1	1
B6	1	0	1	1	0	1	1	1	1	1	0	1	1	1
B7	1	0	0	1	0	0	1	0	0	0	0	0	0	0
B8	1	0	0	1	0	0	1	1	0	0	0	1	0	0
B9	0	0	0	0	0	0	1	1	1	1	1	0	0	0
B10	1	0	1	1	0	0	1	1	0	1	1	1	1	1
B11	1	0	1	1	0	0	1	0	0	0	1	1	1	0
B12	0	0	0	0	0	0	0	0	0	0	0	1	0	0
B13	1	0	1	1	0	0	1	0	1	0	0	0	1	0
B14	1	0	0	1	0	0	1	1	0	0	0	1	1	1

Table 5: FRM.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
B2	1*	1	1	1	1	1	1	1	1	1	1	1	1	1
B3	1	0	1	0	0	0	0	0	0	0	0	1	0	0
B4	1*	0	1	1	0	0	0	0	0	0	0	1	0	0
B5	1	0	1	1	1	1	1*	1	1	1	1	1	1	1
B6	1	0	1	1	0	1	1	1	1	1	1*	1	1	1
B7	1	0	1*	1	0	0	1	0	0	0	0	1*	0	0
B8	1	0	1*	1	0	0	1	1	0	0	0	1	0	0
B9	1*	0	1*	1*	0	0	1	1	1	1	1	1*	1*	1*
B10	1	0	1	1	0	0	1	1	1*	1	1	1	1	1
B11	1	0	1	1	0	0	1	1*	1*	1*	1	1	1	1*
B12	0	0	0	0	0	0	0	0	0	0	0	1	0	0
B13	1	0	1	1	0	0	1	1*	1	1*	1*	1*	1	1*
B14	1	0	1*	1	0	0	1	1	1*	1*	1*	1	1	1

Note: *Values after incorporating the transitivity.

among the identified barriers. The nodes represent the barriers, while the directed links indicate the influence of one barrier over another. Barriers positioned at the lower levels exhibit higher driving power, indicating their strong influence on other interconnected barriers.

The final ISM model (Fig 3) is obtained after removing transitive links from the digraph, thereby retaining only the most meaningful direct relationships among the barriers. This results in a streamlined hierarchical structure that improves clarity and interpretability.

MICMAC analysis

MICMAC analysis is performed to classify the identified barriers based on their driving power and dependence power, using the values derived from the FRM. The analysis groups the barriers into four categories, namely autonomous, dependent, linkage and independent variables, as illustrated in Fig 4.

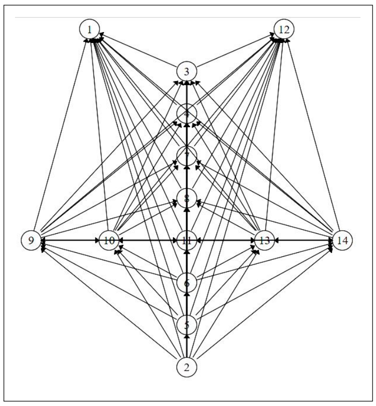

Fig 2: ISM digraph.

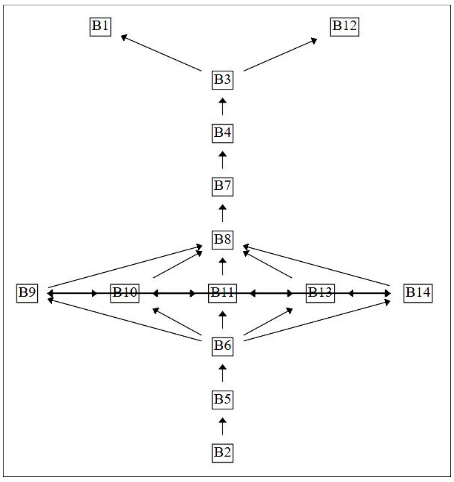

Fig 3: Final ISM model.

RESULTS AND DISCUSSION

The ISM model and MICMAC analysis consistently identify lack of formal RL infrastructure (B2), high cost and low return on investment (B5) and inadequate cold chain facilities (B6) as the most influential barriers. These barriers exhibit high driving power and low dependence, indicating that they form the foundational layer of the system.

The prominence of B2 highlights the structural gap in organizing reverse flows such as collection, aggregation and processing of Agri waste. In the Indian context, the absence of formalized infrastructure leads to inefficiencies and limits scalability of circular practices. Similarly, B5 reflects the economic constraints associated with circular

Table 6: Conical matrix.

Barriers	B1	B12	B3	B4	B7	B8	B9	B10	B11	B13	B14	B6	B5	B2	Driving power	Level
B1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
B12	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
B3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	3	2
B4	1*	1	1	1	0	0	0	0	0	0	0	0	0	0	4	3
B7	1	1*	1*	1	1	0	0	0	0	0	0	0	0	0	5	4
B8	1	1	1*	1	1	1	0	0	0	0	0	0	0	0	6	5
B9	1*	1*	1*	1*	1	1	1	1	1	1*	1*	0	0	0	11	6
B10	1	1	1	1	1	1	1*	1	1	1	1	0	0	0	11	6
B11	1	1	1	1	1	1*	1*	1*	1	1	1*	0	0	0	11	6
B13	1	1*	1	1	1	1*	1	1*	1*	1	1*	0	0	0	11	6
B14	1	1	1*	1	1	1	1*	1*	1*	1	1	0	0	0	11	6
B6	1	1	1	1	1	1	1	1	1*	1	1	1	0	0	12	7
B5	1	1	1	1	1*	1	1	1	1	1	1	1	1	0	13	8
B2	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	14	9
Dependence power	13	13	12	11	10	9	8	8	8	8	8	3	2	1		
Level	1	1	2	3	4	5	6	6	6	6	6	7	8	9		

Note: *Values after incorporating the transitivity.

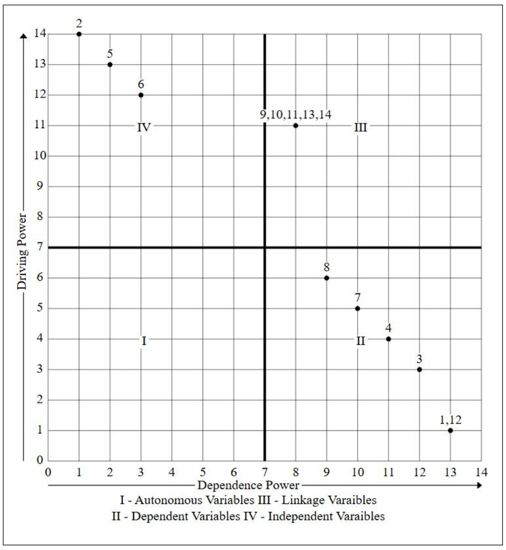

Fig 4: MICMAC analysis.

initiatives, where high initial investments and uncertain returns discourage adoption, particularly among small and medium enterprises. B6 further reinforces the operational dimension, as inadequate cold chain systems result in high perishability losses, thereby reducing the feasibility of recovery and reuse.

CONCLUSION

The ISM model reveals a clear multi-level structure, where influence flows from foundational barriers to intermediate and outcome level barriers. The bottom layers are dominated by infrastructure and financial constraints, followed by a cluster of policy, technological and coordination barriers and finally by farm-level structural and socio-cultural barriers at the top. This layered structure provides important insights for decision making. Addressing higher level barriers without resolving foundational issues may lead to limited impact. The study contributes to the literature by integrating ISM and MICMAC approaches in the context of circular AFSCs, particularly within the Indian setting. It offers a clear hierarchical model that can support policymakers and practitioners in prioritizing interventions and designing targeted strategies for improving RL adoption.

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Disclaimers

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Informed consent

Informed consent and ethical approval are not applicable.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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