Modeling Challenges for Building Technological Capacities to Achieve Sustainability in the Food Industry

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Abstract

The food industry plays a key role in the economy. The high potential of this field and its contribution to sustainable development is revealed by being well equipped with advanced production and management technologies. In developing countries, including India, the sector is insufficiently focused on building this capacity and harnessing its effects for progress.

The saturation of the economy with innovation and communication diversity gives it increased complexity, nonlinearity, interconnectedness and interdependence. Such synergy has two poles. With proper management and holistic coverage of complex systems, it generates a cascade of self-reinforcing positive development processes. However, in their absence, there are large-scale problems that hinder the transition to a «green» model of development, which is especially relevant for the agricultural sector as one of the main pollutants of the environment and the triggers of climate change.

The article analyzes the relationship between the complex problems, assessing their strength of influence, the degree of dependence on other factors. It reveals the «points of application» of efforts, the work with which will launch self-organizing processes, allowing to eliminate other barriers to the goals of sustainable development.

Keywords: economic complexity; interdependencies; innovative technologies; food processing industry; challenges for sustainable development; interpretive structural modeling; MICMAC analysis; India

Citation: Durgaprasad A.V.S., Prasad C.V.V.S.N.V. (2023) Modeling Challenges for Building Technological Capacities to Achieve Sustainability in the Food Industry. *Foresight and STI Governance*, 17(3), 45–55. DOI: 10.17323/2500-2597.2023.3.45.55

Introduction

Sustainability has turned out to be a global necessity for organizations across industries. However, achieving sustainability is a cumbersome task due to multiple challenges. These challenges are industry-specific and their magnitude differs from industry to industry. The food industry is more complicated than other industries because of the perishable nature of the food. Food waste accounts for eight to ten percent of greenhouse gas (GHG) emissions, leading to climate change and extreme weather conditions like droughts and floods. Food waste and GHG emissions account for a good part of environmental damage, such as crop yields and the lower nutritional value of crops, and pose a threat to nutrition and food security (FAO, 2019).

In India, the food processing industry has enormous potential to increase revenue and create jobs (Dharni, Sharma, 2015). India has a considerable resource base in this regard and ranks first in the production of many food items.[1] However, the food processing industries in India face sustainability-related challenges like the lack of food quality, a lack of linkages among the government, farmers, and food processing firms, poor government policies, and a lack of technology adoption (Gardas et al., 2017; Kumar et al., 2020; Sharma et al., 2019; Singh et al., 2021).[2] Thirty to thirty-five percent of food is lost due to inefficient handling, inadequate supply chain infrastructure, and poor transport in India (Parwez, 2016). The other prominent challenges associated with sustainability in the Indian food processing industry are a lack of management commitment toward sustainability and a lack of supply chain collaboration (SCC) (Lahane et al., 2020; Siddh et al., 2021). The rate at which India consumes resources and produces solid waste poses a severe threat to sustainability.

Therefore, it is vital to identify challenges associated with sustainability and understand the complexities among them in the context of the Indian food processing industry. Although many researchers studied challenges in the food industry, very few worked on classifying and prioritizing these challenges.[3] Researchers found a paucity of studies with regard to sustainability in developing countries, particularly in the food industry (Balaji, Arshinder, 2016; Kurniawati et al., 2022).

Considering these gaps, the objectives of this study are to identify the challenges associated with sustainability in the Indian food processing industry, and to analyze the relationships between these challenges, and then prioritize them. Further, Matrices d'Impacts Croises Multiplication Appliqué a un Classement (Cross-impact matrix multiplication applied to classification) (MICMAC) analysis is also carried out to classify these challenges. The findings of this study will strengthen the literature and assist the policymakers at the Indian food processing firms by prioritizing and classifying the sustainability-related challenges.

Challenges Associated with Sustainability

Modern economic systems are characterized by increased complexity, very dense interconnectedness, and interdependence of items and compounds. They tend to distribute resources and opportunities unevenly. Due to a complex combination of factors (favorable conditions for the development of human capital, etc.), developed countries receive more return on their resources by offering a wide range of products produced using a variety of technologies (Balland et al., 2022). There are mutually reinforcing interaction effects (positive feedback loops) between related elements. Thus, strengthening the influence of one problem worsens the situation with another, or, under favorable circumstances, there is a positive synergy between the factors that contribute to economic growth. These patterns are clearly illustrated by the processes taking place in the food industry of developing countries, including India.

Another observation of direct relevance to the issue raised in our paper is that developed economies that are able to deploy more advanced technologies tend to have lower GHG intensity (Romero, Gramkov, 2021). Such an effect is explained by the increased opportunities for highly diversified economies to produce more efficient and environmentally friendly products. These findings are supported by studies on samples from more than 80 countries over the past two decades (Boletti et al., 2021; Neagu, 2019).

This section provides a brief discussion on the challenges associated with sustainability in the Indian food processing industry. Eleven challenges identified through a review of the literature are listed in Table 1. Let us consider them in more detail.

Lack of food quality and safety. The degradation of food quality generally occurs due to improper handling and packaging as well as the lack of temperature-controlled transport and cold storage, while food safety problems arise due to inefficient processing (Marucheck et al.,

[1] India ranks first in the production of milk, tea, spices, cashews, pulses, and sugarcane and second in fruits and vegetables, wheat, and rice. The Indian food processing market may reach $535 billion by 2025-2026. About 1.77 million people are employed in the Indian food industry (IBEF, 2022). For comparison: China is Asia's largest food processing nation, with a revenue of $1,319 billion (https://www.statista.com/outlook/cmo/food/china, accessed 11.06.2023.). Whereas the revenues of a few other Asian nations are as follows: Japan - $651 billion (https://www.statista.com/outlook/cmo/food/japan, accessed 11.06.2023), Russia - $104 billion (https://www.trade.gov/country-commercial-guides/russia-agribusiness, accessed 11.06.2023), South Korea - $99.09 billion (https://www.statista.com/statistics/780672/south-korea-processed-food-market-size/, accessed 11.06.2023), and Malaysia - $49.51 billion (https://www.statista.com/outlook/cmo/food/malaysia/, accessed 11.06.2023).

[2] Most Asian countries have similar challenges, such as underdeveloped supply chain infrastructure and poor government policies (Khan et al., 2022). The food waste in China is around 35 million tons in production, processing, and transportation due to a lack of supply chain infrastructure (Farooque et al., 2019).

[3] Gardas et al. (2018) recommended more studies on challenges in the Indian food industry using Interpretive Structural Modeling (ISM).

Table 1. **Challenges Associated with Sustainability**

Challenges	Source
C1 Lack of food quality and safety	(Jose, Shanmugam, 2020; Kumar et al., 2020; Routroy, Behera, 2017)
C2 Inadequate supply chain infrastructure	(Aggarwal, Srivastava, 2016; Gardas et al., 2018; Kumar et al., 2020; Kumar et al., 2021)
C3 Food waste	(Kumar et al., 2020; Parwez, 2016; Routroy, Behera, 2017)
C4 Improper packaging	(Aggarwal, Srivastava, 2016; Parwez, 2016; Routroy, Behera 2017)
C5 Lack of technology adoption	(Kumar et al., 2021; Naik, Suresh, 2018; Routroy, Behera, 2017; Yadav et al., 2020; Zhu et al., 2018)
C6 Lack of SCC	(Lahane et al., 2020; Parwez, 2016; Yadav et al., 2020)
C7 Poor demand management	(Kumar et al., 2020; Raut, Gardas, 2018)
C8 GHG emissions	(Ghadge et al., 2021; Jose, Shanmugam, 2020; Zhu et al., 2018)
C9 Lack of management commitment towards sustainability	(Lahane et al., 2020; Pullman et al., 2009; Siddh et al., 2021)
C10 Poor government policies	(Kumar et al., 2021; Parwez, 2016; Prakash, 2018; Sharma et al., 2019; Yadav et al., 2020)
C11 Lack of market linkages	(Gardas et al., 2017; Lahane et al., 2020; Naik, Suresh, 2018)
Source: authors.	

2011). If the produced food does not meet the necessary quality and safety guidelines, it leads to food insecurity and scarcity (Trivedi et al., 2019). The consumption of unsafe food harms public health and significantly affects a firm's profits (Akkerman et al., 2010).

Inadequate supply chain infrastructure. The lack of cold storage, refrigerated trucks, proper roads, and proper transportation are supply chain infrastructure problems (Aggarwal, Srivastava, 2016; Kumar et al., 2020). Insufficient cold storage and too few refrigerated trucks affect food quality and shelf life (Dharni, Sharma, 2015). Poor roads and warehousing affects the livelihood of farmers and other intermediaries who are involved in agribusiness (Parwez, 2016).

Food waste. Food waste is a significant challenge faced by food processing firms in India (Parwez, 2016; Routroy, Behera, 2017). Food waste occurs due to inefficient handling, packaging, storage, and demand forecasting (Shukla, Jharkaria, 2013). Food waste results in GHG emissions through landfills, increasing waste disposal costs and reducing profits (Kumar et al., 2020).

Improper packaging. Inappropriate packaging of food products leads to the depletion of quality, the reduction of shelf life, and food waste (Rais, Sheoran, 2015). Non-recyclable packaging damages the ecosystem through litter and leads to environmental degradation. Recycled and eco-friendly packaging will help firms progress in sustainability. Using recyclable materials like cardboard and glass can reduce packaging costs per unit of a product while minimizing the environmental impact (do Canto et al., 2021).

Lack of technology adoption. Indian food processing firms are hesitant to adopt new technologies (Shukla, Jharkharia, 2013). Slow or non-existent technology adoption hinders the organization's growth (Siddh et al., 2017). With mounting consciousness regarding sustainability and consumer apprehensions about food safety, firms face the challenge of choosing the right measures by incorporating technology. The supply chain of food processing firms is extremely complex, unorganized, and involves multiple intermediaries, and they need state-of-the-art technologies like blockchain, which helps improve the coordination among them (Yadav et al., 2020). Gupta et al. (2019) posited that technology reduces environmental risks at the production and processing level and makes the product cheaper, leading to the commercial success of the products.

Lack of SCC. The lack of collaboration among the supply chain members leads to inefficiencies in the supply chain, quality degradation, and food waste (Despoudi et al., 2018). There was a loss of $6.7 billion in the fruit and vegetable sector due to a lack of collaboration among supply chain partners (Balaji, Arshinder, 2016). Strengthening collaboration across the supply chain leads to better demand forecasting and inventory management (Aggarwal, Srivastava, 2016).

Poor demand management. Inaccurate forecasting of consumer demand leads to poor demand management. Poor demand forecasting and management may lead to overstocking, stockouts, increased inventory costs, revenue loss, and food waste (Balaji, Arshinder, 2016). Unintegrated systems and processes and no real-time data sharing lead to poor demand and inventory management (Raut, Gardas 2018). Close collaboration with supply chain members is a prerequisite for proper demand management, which helps in averting food waste (Mena et al., 2014).

GHG emissions. GHG emissions are one of the most significant challenges faced by food processing firms. Food processing firms generate GHG emissions throughout their operations, especially during transportation and distribution. These emissions adversely impact ecology and contribute to climate change and pollution (Sharma et al., 2019).

Lack of management commitment toward sustainability. Management commitment toward sustainability is an important factor in achieving sustainability at an organization (Pullman et al., 2009). Lack of management commitment toward sustainability leads to many inefficiencies at firms with regard to social, economic, and environmental factors. Management often disregards sustainability as there are no immediate financial gain and clear involvement of higher costs (Siddh et al., 2021). Sustainability in the food processing industry is primarily driven by management commitment (Ghadge et al., 2021).

Poor government policies. In developing nations like India, poor government policies are a major obstacle to sustainability. Government support is necessary to

Table 2. **Experts Profile**

№	Experience in years	Role
		Food Industry
1	8	Operations Manager
2	15	Managing Director
3	7	Junior Manager
4	8	Supply Chain Manager
5	9	Senior Manager
6	13	Procurement Head
		Academia
7	11	Assistant Professor
8	12	Assistant Professor
9	15	Professor

Source: authors..

develop infrastructure facilities like roads, cold storage, and financial aid for food processing firms (Singh et al., 2021). Government policies are essential enablers of sustainability in the food industry (Kumar et al., 2020). Proper government policies help reduce inefficiencies, food waste, and GHG emissions (Sharma et al., 2019).

Lack of market linkages. Poor access to the market, the lack of multiple marketing channels, and the lack of organized supply chains are some barriers to sustainability in developing nations like India (Negi, Anand, 2015; Parwez, 2016). In India, there are not many direct linkages between farmers and processing firms, and the marketing channels are long due to multiple intermediaries, which leads to a depletion in product quality, leading to higher procurement costs for processing firms while fetching lower prices for farmers (Gardas et al., 2017).

Box 1. **Steps in ISM**

- Variables related to the problem are listed using either primary or secondary research.
- Using expert opinion, the structural self-interaction matrix (SSIM) establishes interrelationships among the variables using V, A, X, and O.
- Developing the initial reachability matrix (IRM) by transforming SSIM from V, A, X, and O to 0,1.
- Developing the final reachability matrix (FRM) by checking for transitivity in the IRM. Transitivity in ISM implies that if C1 and C2 are related, C2 and C3 are related, then C1 and C3 are related.
- Formation of different levels through partitioning FRM.
- Formation of digraph
- An ISM model is formed by substituting the nodes of digraphs with the variables in the study. Thus, a prioritization model of hierarchy is created.
- The model is looked over to see if there are any conceptual inconsistencies..

Source: authors.

Methodology

This study employed the ISM-MICMAC methodology to meet the research objectives. In the first stage, thirteen significant challenges pertinent to the food processing firm were identified through literature searches.[4] Following a literature review, the research problem underwent brainstorming sessions with experts from academic and industrial organizations to validate the identified challenges in an Indian setting. The participants in the study consist of six food industry professionals and three academicians. Table 2 depicts the experts' profile. Finally, eleven challenges that emerged from the literature review were retained and others were left out as they were overlapping and not unique. Further, the experts assisted in forming the interrelationships among the identified challenges.

ISM Analysis

ISM methodology is used to identify relationships between the variables of interest and present the variables in order of priority. Weakly articulated conceptual schemas of systems are transformed into explicit and well-defined models through ISM (Attri et al., 2013). Hierarchical arrangements of variables corresponding to a specific problem can be predicted using ISM. There are many complex challenges associated with sustainability in the food processing industry and ISM assists in dealing with complex relationships among the various variables under examination (Bhadani et al., 2016). Steps in ISM are represented in Box 1.

MICMAC Analysis

MICMAC is built on a matrix multiplication property (Sharma et al., 1995). MICMAC analysis classifies the identified challenges that drive the system into four groups (Bhadani et al., 2016). Challenges are plotted subject to their dependence and driving power, ranging from 0 to the total number of challenges. The plotted values are represented in four quadrants on horizontal and vertical axes bifurcated at mid-points.

ISM aids in bringing together fragmented and scattered knowledge and creating cohesive and actionable information. Hence, it is instrumental in inherently multidisciplinary areas, such as sustainability. ISM, used in tandem with MICMAC, is an engaging tool for visualizing the challenges and relationships among various factors (Ahmad, Qahmash, 2021). ISM is distinct and superior to other multiple criteria decision-making techniques as it establishes relationships and prioritizes the identified variables using a group of experts, which helps one interpret complex real-life problems easily (Mangla et al., 2018; Soni et al., 2020).

[4] The following keywords were used: 'challenges', 'issues', 'barriers', 'food processing', ,agri-food', 'food supply chain', 'sustainability'.

Table 3. **SSIM Matrix**

№	Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	Lack of food safety and quality	1	A	V	A	A	A	A	V	A	A	A
C2	Inadequate supply chain infrastructure		1	V	V	O	A	O	V	A	A	X
C3	Food waste			1	A	O	A	A	V	A	A	A
C4	Improper packaging				1	A	A	O	V	A	A	A
C5	Lack of technology adoption					1	A	V	V	A	A	A
C6	Lack of SCC						1	V	V	A	A	A
C7	Poor demand management							1	V	A	A	A
C8	GHG emissions								1	A	A	A
C9	Lack of management commitment towards sustainability									1	A	O
C10	Poor government policies										1	V
C11	Lack of market linkages											1

Note: V specifies challenge i helps to reach challenge j; A specifies challenge j helps to reach challenge i.; X specifies challenges i and j complement each other; O specifies challenges i and j are not associated.
Source: authors.

Hence, ISM – MICMAC is an appropriate technique for this study.

Results

SSIM, IRM, and FRM Analyses

SSIM is formulated from the eleven challenges identified in Table 1. V, A, X, and O specify the relationships among the challenges. SSIM is shown in Table 3.

The IRM is formed by transforming SSIM in accordance with the following guidelines. The IRM is shown in Table 4.

After applying transitivity, the IRM is transformed into the FRM. In this study, C6-C5 is allotted as 1, demonstrating their relationship. C6 has a relationship with C3, but C5 does not have a relationship with C3. After applying the concept of transitivity, the cell C5-C3 changes from 0 to 1* in the FRM. Similarly, transitivity is checked for all other challenges. The FRM is illustrated in Table 5.

Level Partition

The FRM is divided into a reachability set, an antecedent set, and an intersection set for the formation of levels. The reachability set is defined as challenges that a particular challenge can reach. Similarly, an antecedent set is a set of challenges that reach a specific challenge. The challenges commonly present in the reachability and antecedent sets are listed in the intersection set. A level is formed when a challenge has the same reachability and intersection set. Then those challenges are eliminated from each challenge's reachability and antecedent sets. Several iterations were performed on the reachability and antecedent sets to arrive at the

Table 4. **IRM Matrix**

№	Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	Lack of food safety and quality	1	0	1	0	0	0	0	1	0	0	0
C2	Inadequate supply chain infrastructure	1	1	1	1	0	0	0	1	0	0	1
C3	Food waste	0	0	1	0	0	0	0	1	0	0	0
C4	Improper packaging	1	0	1	1	0	0	0	1	0	0	0
C5	Lack of technology adoption	1	0	0	1	1	0	1	1	0	0	0
C6	Lack of SCC	1	1	1	1	1	1	1	1	0	0	0
C7	Poor demand management	1	0	1	0	0	0	1	1	0	0	0
C8	GHG emissions	0	0	0	0	0	0	0	1	0	0	0
C9	Lack of management commitment towards sustainability	1	1	1	1	1	1	1	1	1	0	0
C10	Poor government policies	1	1	1	1	1	1	1	1	1	1	1
C11	Lack of market linkages	1	1	1	1	1	1	1	1	0	0	1

Note: V: Entry in the grid (i, j) becomes 1, and the entry in the grid (j, i) becomes 0; A: Entry in the grid (i, j) becomes 0, and the entry in the grid (j, i) becomes 1; X: Both the entries (i, j) and (j, i) become 1; O: Both the entries (i, j) and (j, i) become 0.
Source: authors..

Table 5. **FRM Matrix**

№	Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	Driving Power
C1	Lack of food safety and quality	1	0	1	0	0	0	0	1	0	0	0	3
C2	Inadequate supply chain infrastructure	1	1	1	1	1*	1*	1*	1	0	0	1	9
C3	Food waste	0	0	1	0	0	0	0	1	0	0	0	2
C4	Improper packaging	1	0	1	1	0	0	0	1	0	0	0	4
C5	Lack of technology adoption	1	0	1*	1	1	0	1	1	0	0	0	6
C6	Lack of SCC	1	1	1	1	1	1	1	1	0	0	1*	9
C7	Poor demand management	1	0	1	0	0	0	1	1	0	0	0	4
C8	GHG emissions	0	0	0	0	0	0	0	1	0	0	0	1
C9	Lack of management commitment towards sustainability	1	1	1	1	1	1	1	1	1	0	1*	10
C10	Poor government policies	1	1	1	1	1	1	1	1	1	1	1	11
C11	Lack of market linkages	1	1	1	1	1	1	1	1	0	0	1	9
	Dependence Power	9	5	10	7	6	5	7	11	2	1	5	

Source: authors.

levels of challenges. Partitioning the reachability matrix into levels along with iterations is presented in the Appendix. This model contains eight levels of challenges, as depicted in Table 6.

ISM Model

The digraph is developed from the FRM, depicting the relationships between the challenges, as shown in Figure 1. The transitivity links in the digraph are removed and transformed into an ISM model, which depicts the prioritization of challenges as presented in Figure 2. The findings revealed that poor government policies at Level 8 and the lack of management commitment toward sustainability at the Level 7 are the most significant challenges faced by the Indian food processing industry and impact other challenges. As a top-level challenge, GHG emissions are driven by all other challenges. The bottom-level challenges in the ISM are of the highest importance. The challenges present at the bottom significantly impact the challenges above them in the hierarchy. Government policies bring a change in management commitment which results in better SCC and improvement in the supply chain infrastructure and market linkages. SCC leads to technology adoption among the firms, leading to improved demand management and packaging. Thus, these lead to better food quality and safety, reducing food waste and GHG emissions.

MICMAC Analysis

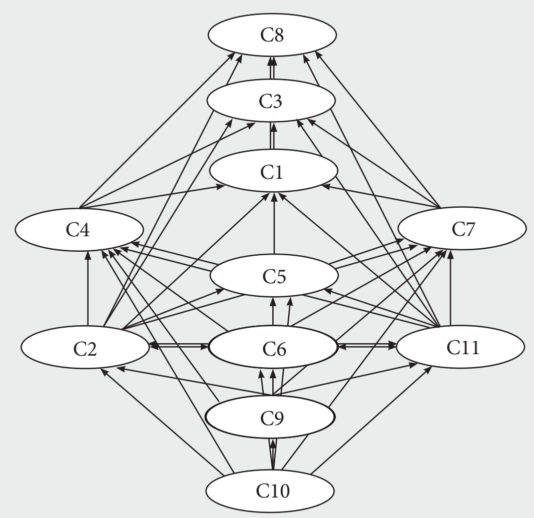
This method determines the driving power and dependence power of each challenge for further insights regarding these challenges. The challenges were divided into four clusters built on dependence and driving power, visually represented in four quad-

Table 6. **Levels of Challenges**

№	Challenge	Level
C1	Lack of food safety and quality	3
C2	Inadequate supply chain infrastructure	6
C3	Food waste	2
C4	Improper packaging	4
C5	Lack of technology adoption	5
C6	Lack of SCC	6
C7	Poor demand management	4
C8	GHG emissions	1
C9	Lack of management commitment towards sustainability	7
C10	Poor government policies	8
C11	Lack of market linkages	6

Source: authors.

Figure 1. **Digraph of challenges associated with sustainability in the Indian food processing industry**



Source: authors..

rants, as shown in Figure 3. A description of the challenges' distribution within the quadrants is presented in Table 7.

Implications and Conclusion

This study has identified and analyzed the relationships among the challenges associated with sustainability in the Indian food processing industry. Eleven sustainability-related challenges were identified for this purpose. Further, a model was developed for prioritizing the challenges using the ISM approach. MICMAC analysis was also employed to categorize the challenges based on their dependence and driving power. The observations of this study will deliver profound insights to managers, policymakers, and decision-makers who plan to overcome sustainability-related challenges at their organizations.

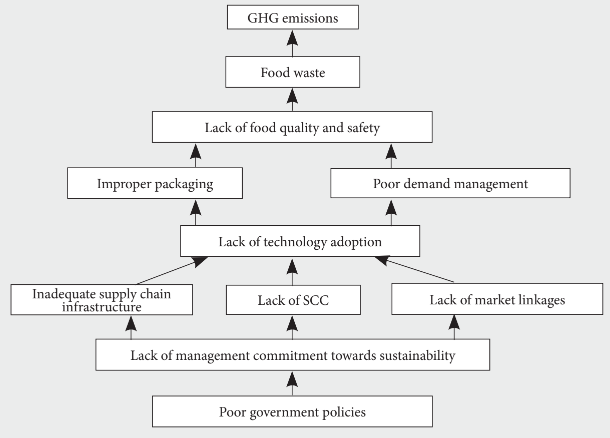
Findings from the ISM reveal eight levels of sustainability-related challenges. Poor government policies and the lack of management's commitment toward sustainability are the key challenges at Levels 8 and 7, respectively, as shown in Figure 2. Therefore, the managers should prioritize these two challenges as addressing these would aid in overcoming other challenges for the food processing firms. It is evident from the MICMAC analysis that challenges such as lack of food quality and safety, food waste, improper packaging, GHG emissions, and poor demand management are heavily dependent on other challenges such as poor government policies and regulations, the lack of management's commitment toward sustainability, the lack of market linkages, the lack of SCC, and the lack of supply chain infrastructure. Thus, management should focus on the challenges with strong driving power as they have a greater capacity to influence challenges with weak driving power.

The outcomes are consistent with those of earlier research, which identified a lack of SCC, inadequate supply chain infrastructure, poor government policies, technology adoption, and food waste as major challenges in the food industry (Sharma et al., 2019). The present study also resonates with a study on Chinese food supply chains, where the authors revealed limited technology adoption, organizational management, weak environmental regulations, and the lack of SCC as the barriers to sustainability (Farooque et al., 2019). It can be deduced that the challenges at the foot of the ISM model are the origins of other challenges.

Government policies play an essential role in changing management's commitment toward sustainability, leading to the improvement in sustainability at the firm. Apart from the role played by the state, the municipal authorities also need to act responsibly by improving the market linkages across the chain and facilitating the ease of doing business in the food industry, opening the market for food processing firms that can invest in supply chain infrastructure. The experts concurred that effective government policies combined with local governance are required to develop supply chain infrastructure. Municipal authorities could also create awareness among the firms and consumers regarding the importance of sustainability.

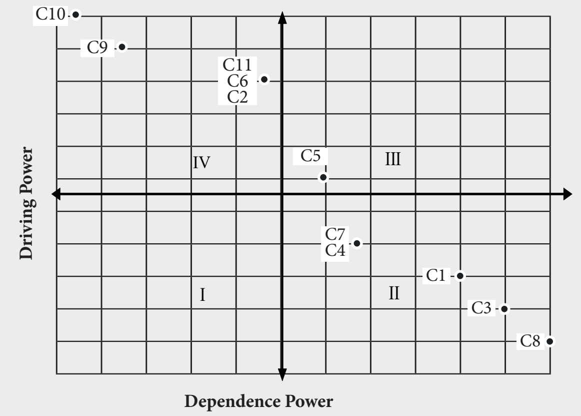
From the organizational context, management commitment toward sustainability, lack of technology adoption, lack of SCC, poor demand management, and improper packaging are the important issues to be addressed by the managers of the food processing industry. Top management commitment is crucial for achieving sustainability at the firm level. Food processing organizations need to use advanced technologies to improve food quality and reduce food waste. Technology adoption enhances and facilitates information sharing across the supply chain, improving supply chain collaboration and resulting in better demand forecasting. Technology itself is not transformative, but when accompanied by effective governance, it becomes crucial to address the needs of society. Technology accelerates the growth of the entire global food value chains by

Figure 2. **ISM Model**



Source: authors.

Figure 3. **Driver - Dependence matrix**



Source: authors.

Table 7. **Challenges' distribution by type**

Quadrant	Driving / dependence power ratio	Nature of challenges	Challenges included
I – Autonomous challenges	Weak / weak	These challenges remain unaffected and do not impact other challenges	—
II – Dependent challenges	Weak / strong	The challenges that highly depend on other challenges in the study	• Lack of food quality and safety • Food waste • Improper packaging • GHG emissions • Poor demand management
III – Linkage challenges	Strong / strong	These challenges are unstable and affect other challenges	• Lack of technology adoption
IV ¬– Independent challenges	Strong / weak	These challenges must be given more attention as they help overcome other challenges	• Poor government policies • Lack of management commitment towards sustainability, • Lack of market linkages • Lack of SCC • Inadequate supply chain infrastructure

Source: authors..

adding value to the product at each stage of supply chain (Katalevsky, 2022). Government policies that incentivize low-carbon technology have the potential to expedite the transition toward a more sustainable food design (Herrero et al., 2020).

The present study substantially contributes to the domain of sustainability through a comprehensive understanding of the challenges in the food processing sector. The prioritization of challenges will help managers focus on the challenges of the highest importance in overcoming sustainability-related challenges. The study's findings will also assist the government in developing policies in order to address the challenges associated with sustainability. Furthermore, the classification of challenges using a MICMAC analysis helps the food processing firms to identify the challenges in accordance with driving power and dependence, which helps one to manage the challenges effectively. Though the challenges are prioritized from the Indian perspective, the approach may also be applied to other developing nations.

Although several contributions are made, this study has limitations. Logistical and infrastructural challenges that seem to act as impediments to sustainability would likely be mitigated with time as India moves up the development ladder. The relationships among the challenges were created based on the knowledge of the experts, which is subjective. Also, the challenges presented in the study may not be exhaustive; future research may uncover other relevant challenges. As for the methodological aspect, experts' prejudices may affect the ISM. Fuzzy theory can be added to the methodology to resolve this issue. This study employed nine experts to apply the ISM methodology. Future studies may use a larger number of experts for more robust validation. Future researchers should employ alternative approaches like fuzzy MICMAC and total interpretive structural modeling to gain additional insights.

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Appendix 1. **Iterations for level partitioning**

№	Challenge	Reachability set	Antecedent set	Intersection set
		Level 1		
C1	Lack of food safety and quality	1, 3, 8	1, 2, 4, 5, 6, 7, 9, 10, 11	1
C2	Inadequate supply chain infrastructure	1, 2, 3, 4, 5, 6, 7, 8, 11	2, 6, 9, 10, 11	2, 6, 11
C3	Food waste	3, 8	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	3
C4	Improper packaging	1, 3, 4, 8	2, 4, 5, 6, 9, 10, 11	4
C5	Lack of technology adoption	1, 3, 4, 5, 7, 8	2, 5, 6, 9, 10, 11	5
C6	Lack of SCC	1, 2, 3, 4, 5, 6, 7, 8, 11	2, 6, 9, 10, 11	2, 6, 11
C7	Poor demand management	1, 3, 7, 8	2, 5, 6, 7, 9, 10, 11	7
C8	GHG emissions	8	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	8
C9	Lack of management commitment towards sustainability	1, 2, 3, 4, 5, 6, 7, 8, 9, 11	9, 10	9
C10	Poor government policies	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	10	10
C11	Lack of market linkages	1, 2, 3, 4, 5, 6, 7, 8, 11	2, 6, 9, 10, 11	2, 6, 11
		Level 2		
C1	Lack of food safety and quality	1, 3	1, 2, 4, 5, 6, 7, 9, 10, 11	1
C2	Inadequate supply chain infrastructure	1, 2, 3, 4, 5, 6, 7, 11	2, 6, 9, 10, 11	2, 6, 11
C3	Food waste	3	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	3
C4	Improper packaging	1, 3, 4	2, 4, 5, 6, 9, 10, 11	4
C5	Lack of technology adoption	1, 3, 4, 5, 7	2, 5, 6, 9, 10, 11	5

C6	Lack of SCC	1, 2, 3, 4, 5, 6, 7,11	2, 6, 9, 10, 11	2, 6, 11
C7	Poor demand management	1, 3, 7	2, 5, 6, 7, 9, 10, 11	7
C9	Lack of management commitment towards sustainability	1, 2, 3, 4, 5, 6, 7, 9, 11	9, 10	9
C10	Poor government policies	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	10	10
C11	Lack of market linkages	1, 2, 3, 4, 5, 6, 7, 11	2, 6, 9, 10, 11	2, 6, 11
Level 3				
C1	Lack of food safety and quality	1	1, 2, 4, 5, 6, 7, 9, 10, 11	1
C2	Inadequate supply chain infrastructure	1, 2, 4, 5, 6, 7, 11	2, 6, 9, 10, 11	2, 6, 11
C4	Improper packaging	1, 4	2, 4, 5, 6, 9, 10, 11	4
C5	Lack of technology adoption	1, 4, 5, 7	2, 5, 6, 9, 10, 11	5
C6	Lack of SCC	1, 2, 4, 5, 6, 7,11	2, 6, 9, 10, 11	2, 6, 11
C7	Poor demand management	1, 7	2, 5, 6, 7, 9, 10, 11	7
C9	Lack of management commitment towards sustainability	1, 2, 4, 5, 6, 7, 9, 11	9, 10	9
C10	Poor government policies	1, 2, 4, 5, 6, 7, 9, 10, 11	10	10
C11	Lack of market linkages	1, 2, 4, 5, 6, 7, 11	2, 6, 9, 10, 11	2, 6, 11
Level 4				
C2	Inadequate supply chain infrastructure	2, 4, 5, 6, 7, 11	2, 6, 9, 10, 11	2, 6, 11
C4	Improper packaging	4	2, 4, 5, 6, 9, 10, 11	4
C5	Lack of technology adoption	4, 5, 7	2, 5, 6, 9, 10, 11	5
C6	Lack of SCC	2, 4, 5, 6, 7,11	2, 6, 9, 10, 11	2, 6, 11
C7	Poor demand management	7	2, 5, 6, 7, 9, 10, 11	7
C9	Lack of management commitment towards sustainability	2, 4, 5, 6, 7, 9, 11	9, 10	9
C10	Poor government policies	2, 4, 5, 6, 7, 9, 10, 11	10	10
C11	Lack of market linkages	2, 4, 5, 6, 7, 11	2, 6, 9, 10, 11	2, 6, 11
Level 5				
C2	Inadequate supply chain infrastructure	2, 5, 6, 11	2, 6, 9, 10, 11	2, 6, 11
C5	Lack of technology adoption	5	2, 5, 6, 9, 10, 11	5
C6	Lack of SCC	2, 5, 6, 11	2, 6, 9, 10, 11	2, 6, 11
C9	Lack of management commitment towards sustainability	2, 5, 6, 9, 11	9, 10	9
C10	Poor government policies	2, 5, 6, 9, 10, 11	10	10
C11	Lack of market linkages	2, 5, 6, 11	2, 6, 9, 10, 11	2, 6, 11
Level 6				
C2	Inadequate supply chain infrastructure	2, 6, 11	2, 6, 9, 10, 11	2, 6, 11
C6	Lack of SCC	2, 6, 11	2, 6, 9, 10, 11	2, 6, 11
C9	Lack of management commitment towards sustainability	2, 6, 9, 11	9, 10	9
C10	Poor government policies	2, 6, 9, 10, 11	10	10
C11	Lack of market linkages	2, 6, 11	2, 6, 9, 10, 11	2, 6, 11
Level 7				
C9	Lack of management commitment towards sustainability	9	9, 10	9
C10	Poor government policies	9, 10	10	10
Level 8				
C10	Poor government policies	10	10	10
Source: authors.				