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Climate neutrality in agriculture food supply chain: an integrated WINGS-GRID framework

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Abstract

Purpose – Substantial pressure from civil society and investors has forced governments around the world to take climate neutrality initiatives. Several countries have pledged their nationally determined contributions towards net-zero. However, there exist various obstacles to achieving the same and the agriculture sector is one of them. Thus, this study identifies and models the critical barriers to achieving climate neutrality in the agriculture food supply chain (AFSC).

Design/methodology/approach – Sixteen barriers are identified through a literature survey and are validated by the questionnaire survey. Furthermore, the interactions amongst the barriers are estimated through the application of the "weighted influence non-linear gauge system (WINGS)" method which considers the both intensity of influence and the strength of the barrier. To mitigate these barriers, a framework based on green, resilient and inclusive development (GRID) is proposed.

Findings – The obtained results reveal that lack of collaboration amongst AFSC stakeholders, lack of information and education awareness, and lack of technical expertise obtained a higher rank (amongst the top five) in three indicators of the WINGS method and thus are the most significant barriers.

Originality/value – This paper is the first attempt in modelling the climate neutrality barriers for the Indian AFSC. Additionally, the mitigating strategies are prepared using the GRID framework.

Keywords Agriculture food supply chain, Barriers, Climate neutrality, GRID framework, WINGS method

Paper type Research paper

1. Introduction

In recent years, the world is facing two major global issues, i.e. resource consumption and climate change. These issues could be only dealt with through a cohesive effort by the international community. Sustainable development goals (SDGs) and net-zero are prominent initiatives where SDG aims to have sustainable developments through its 17 specific goals while net-zero refers to cutting down the greenhouse gases (GHGs) emission as much as possible while re-absorbing the remaining emissions from the atmosphere through forests and oceans. The idea of achieving net-zero GHG emissions is also referred to as climate neutrality. It is a broader term than carbon neutrality since climate neutrality not only includes the removal of emissions related to carbon but also other GHGs like methane and nitrous oxide which are more dangerous than carbon over a longer period of time (UN Climate Action, 2022). In simple terms, climate neutrality is an ideal state where a firm's or individual's emissions of GHGs are balanced out by removing a similar amount of GHGs from the environment.

Climate neutrality could be achieved by shifting to low-carbon technologies, decarbonization, reducing emissions and offsetting the remaining emissions by buying carbon credits or making use of carbon sinks (Ghosh *et al.*, 2020). GHG emissions are classified under three categories where first category account for emission from sources that

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are owned or controlled by the organization. It is a direct source of emission and is also known as scope 1 emission, whereas scope 2 emission is related to energy/electricity purchased by the organization but not owned by them. Scope 3 emissions are related to all other supporting activities of an organization not owned or controlled by them. Both scopes 2 and 3 are indirect emissions. GHG emission is responsible for air pollution and this causes 4.2 million deaths globally due to chronic diseases (WHO, 2022). The energy sector produces two-thirds of total GHG emissions and hence, is the biggest culprit of climate change (International Energy Agency, 2021). This is important to understand that to preserve our livable planet and address the climate change issue, the global temperature should not exceed 1.5 °C above pre-industrial levels (UN Climate Action, 2022).

At present, Mother Earth is 1.1 °C warmer than it used to be in the late 1800s. Hence, a proposal was made in the Paris Agreement that net-zero should be achieved by 2050 while 45% of emission is to be reduced by 2030. Furthermore, the Glasgow Climate Pact also emphasized the need to attain net-zero emissions. The United Kingdom, the United States and the European Union (EU) have pledged to attain this target by 2050 while China and the Russian Federation have set their deadline to 2060 (Economic Survey, 2022–23, p. 217). India's target to become carbon neutral is by 2070 (Economic Survey, 2022–23, p. 216). However, carbon-neutral is not the complete solution for climate change, and hence, the need for climate neutrality is felt which considers the removal of all GHG emissions. Transition to climate neutrality is the most pressing issue and failure to do so will result in severe loss to nature as well as humankind. Hence, low carbon economies and cleaner air are firmly encountered through sustainable development goal at UN levels and offer a promising and shared blueprint for the planet, people, peace, prosperity and partnership.

At the global level, 24% of GHG emissions are linked with agriculture, forestry and other land use sector which is mostly related to agriculture (IPCC, 2014). Agriculture leads to deforestation and changes the pattern of land use which further results in emitting of GHGs. This sector is the largest contributor of nitrous oxide (due to the use of fertilizers) and methane (due to livestock production) in India (World Economic Forum, 2021). Furthermore, emission is not just observed at land use for agriculture rather significant emission is seen across processing, distribution, consumption and end of life (food waste) across the whole food chain. A report by Boston Consulting Group (Burchardt *et al.*, 2021) reveals that end-to-end emissions from the supply chain are significantly higher than the direct emissions by in-house activities of parent organizations. Additionally, it is estimated the demand for food items will further increase as the projected estimated population is ten billion by 2058 (Worldometer, 2023). Elferink and Schierhorn (2016) believed that world demand for food is expected to increase by 59%–98% by 2050. Meeting such huge demand would be difficult for the present agriculture food supply chain (AFSC) due to the disturbance caused by climate change. On the contrary, the agriculture sector plays a dual role, i.e. though it produces GHG emissions, it also absorbs GHG emissions. A few initiatives of climate neutrality in the agriculture sector include better farming practices for enhancing biodiversities such as mixed farming, organic farming, agroforestry and agroecology; effective resource utilization of energy sources, fertilizers and other farm inputs; production of those crops and livestock that minimizes GHG emissions and incorporating carbon sequestering practices. Tillage is an important consideration in reducing methane emissions. These climate neutrality initiatives are required and some agriculture industries are also focusing on long-term goals to adopt carbon-neutral strategies (Acampora *et al.*, 2023). For this, industries are implementing solutions through they can first reduce to low carbon and align themselves with their long-term vision of climate neutrality. However, adopting climate neutrality is challenging along the AFSC due to significant GHG emissions in the treatment of soil through nitrogen fertilizers, emissions of methane from the ruminant's digestive processes, emissions due to slurry management and the fuel used in machinery, transportation and cold storage, etc.

India is an agrarian economy where 47% of Indians are associated with agriculture (Economic Survey, 2022–23, p. 200). In 2020–2021, India exported agricultural products worth more than $50.2 billion (Economic Survey, 2022–23, p. 243). However, climate change has started affecting the Indian agriculture sector such as irregular rain, floods in different parts of the country and extreme heat which have severely affected the production of food grain; this will also directly affect the world for their food requirement since India is an important food supplier to the world. Hence, the Indian AFSC needs to adopt the climate neutrality initiative to safeguard its people and meet the food demand for everyone. In the Indian context, climate neutrality initiatives are more challenging due to the structure of AFSC which is very complex, bureaucratic and involves many intermediaries (Yadav *et al.*, 2022). This results in the emitting of a significant amount of GHGs at each stage of AFSC. Furthermore, due to a lack of resources, technological infrastructure, information and awareness; Indian AFSC stakeholders are unable to take climate neutrality initiatives. Along with this, there exist several more roadblocks to climate neutrality in AFSC and hence, there is a need to understand and investigate these barriers to make suitable strategies for eliminating them. In literature, there's a dearth of studies on climate neutrality for AFSC. The existing literature presents an overview of the few challenges but lacks an understanding of the interrelationship between the barriers. For, e.g. financial constraint (Mishra *et al.*, 2022; Zhu and Geng, 2013) is a barrier impeding the implementation of climate neutrality initiatives and is responsible for lack of infrastructure (Kumar *et al.*, 2021; Mishra *et al.*, 2022; Zhang *et al.*, 2022a) and lack of investment in green technologies (Kumar *et al.*, 2023a, b; Mishra *et al.*, 2022). Similarly, lack of information and education awareness (Kumar *et al.*, 2023a, b; Vimal *et al.*, 2022; Zhu and Geng, 2013) have influence over lack of technical knowledge (Del Giudice *et al.*, 2021; Mishra *et al.*, 2022; Zhang *et al.*, 2022a) and unclear benefits (Papadis and Tsatsaronis, 2020; Zhu and Geng, 2013) about climate neutrality initiatives. Thus, it is observed that, the impeding barriers have interrelationship which needs to be investigated. Additionally, these barriers need to be eliminated to implement the climate neutrality initiatives. Hence, a need arises to identify the barriers, study the interrelationships so that strategies could be formulated to overcome them for successful implementation of climate neutrality initiatives in AFSC. Thus, the present article aims to answer the following research questions (RQ):

RQ1. What are the barriers impeding climate neutrality in Indian AFSC?

RQ2. What kind of interrelationships prevail among these barriers?

RQ3. What strategies should be adopted for overcoming the climate neutrality barriers in the Indian AFSC?

By answering the above RQs, the present work has threefold contributions: first, enriching and extending the literature on climate neutrality through the identification of barriers with respect to developing countries and by considering several AFSC stakeholders' opinions. This also addresses the existing gaps in the literature about finding the obstacles to achieving climate neutrality so that subsequent mitigating strategies could be formulated. The knowledge of significant barriers and their interactions with other barriers would help the farmers, middlemen, processors, distributors, retailers, consumers and government agencies in the assessment of their readiness to reap the benefits of climate neutrality. The second contribution lies in the application of the "weighted influence non-linear gauge system (WINGS)" method to develop a complete structural model and estimate the cause–effect relationship between the barriers by drawing the influence map. This knowledge could be utilized to prioritize the efforts required for each identified barrier, and subsequent mitigation strategies could be undertaken. The third contribution lies in making the GRID framework, involving green, resilient and inclusive as its main pillar to suggest the strategies for overcoming the identified barriers. Through this, the present study proposes to leverage climate financing and foster digitization and technical solutions for making the existing AFSC more resilient. Educating AFSC stakeholders and creating awareness is another important learning outcome of the present work which requires significant government attention to achieve the target of net-zero.

The article is arranged as follows. The extant literature is reviewed in section 2 and section 3 presents research methodology. Data collection and analysis is given in section 4 while results and strategies to eliminate the identified barriers are discussed in sections 5 and 6, respectively. The concluding remarks are made in section 7.

2. Literature review

Research on net-zero is still in its infancy and is expected to get a lot of attention from the government, industries and academia (Mishra *et al.*, 2022). At the international level, climate-neutrality issues have been pushed at several Conference of the Parties (COP) meetings and some significant developments are being made mostly by developed nations and the EU while 137 countries have committed to achieving net-zero (Mishra *et al.*, 2022). However, efforts by emerging and developing countries are not very prominent. At the industry level, several food sector companies have declared their net-zero initiatives. For example, Nestle is promoting the use of eco-friendly ingredients and transitioning towards a regenerative food system. PepsiCo has doubled down its goal of climate change and aims to achieve net-zero through renewable electricity sources. Furthermore, the world witnessed carbon-neutral coffee for the first time originating from Costa Rica. Birkenberg and Birner (2018) studied the certification and innovation involved in doing this and reported the challenges faced by the concerned organization and solutions were also discussed. Ofori *et al.* (2023) discussed the role of governance indicators and financial development in achieving carbon neutrality in MINT (Mexico, Indonesia, Nigeria and Turkey), BRICS (Brazil, Russia, India, China and South Africa) and G7 (Group of 7) economies. The study showed a positive effect of governance indicators on environmental sustainability while financial development had a mixed effect on environmental degradation. Additionally, the role of startups is also crucial in developing climate innovation. The startups were estimated to have a value of 27 billion Euro during 2000–22 and amongst them, the highest climate innovation was observed in the food sector (24%) (Hakovirta *et al.*, 2022).

Obtaining net-zero is unrealistic and hence, offsetting is required (emissions minus offsets). Carbon neutrality, decarbonization or switching to low-carbon solutions are some of the initiatives undertaken by various firms and are being studied by researchers. Achieving carbon neutrality enhances the firm economic performance among the first mover organization (Zhang *et al.*, 2022b). A few drivers of carbon neutrality given by Zhang *et al.* (2022b) include “customer enforcement”, “environmental legitimacy” “sustainable business value”, “long-term economic benefits” and “competitive pressures”. These drivers have implications for the supply chain and these implications were also discussed in their study. However, decarbonizing supply chain faces critical impediments and was studied in another work by Zhang *et al.* (2022a) through the case study of six industries which had first movers’ advantage towards carbon neutrality and found that economic performance of these industries is improved. The six firms represented industries from the food, textile, beverages, transport and logistics sectors. The study reported a few common barriers to carbon neutrality such as “major upfront investment costs,” “lack of awareness,” “lack of expertise” and “resistant mindset.” Additionally, the SMEs faced impediments including “lack of support from supply chain partners” and “uncertainty in return on investment.” Kumar *et al.* (2023a, b) investigated the barriers related to low carbon operations from an emerging country’s perspective. Thirty-one barriers under seven heads were identified and obtained results suggested that barriers belonging to the economic, infrastructural and operational categories were the most influential barriers. A detailed discussion on drivers and barriers to carbon neutrality in the agri-food sector is carried out by Acampora *et al.* (2023). The extant literature has limited studies on identifying the critical impediments to climate neutrality. Also, the existing literature mostly discusses manufacturing and related industries. The work in the agriculture domain is given the least emphasis except in one study by Zhang *et al.* (2022a). Another important aspect that is missing from the literature is the modelling of climate neutrality barriers as the existing literature only discusses decarbonization. In addition to this, concrete strategies are missing to eliminate the barriers. In this work, an effort is made to address all these gaps in the literature. In doing so, the first step is the identification of barriers (more on this is provided in the research methodology section) which was carried through an exhaustive review process and was validated by domain experts (details in Tables 2 and 3); a summary of climate neutrality barriers collected from the literature review is mapped and mentioned in Table 1.

2.1 Challenges for adopting climate neutrality in AFSC

Lack of strong policy: Lack of a strong policy framework limits the climate neutrality initiatives by concerned AFSC stakeholders (Kumar *et al.*, 2023a, b; Mishra *et al.*, 2022; Subramanian and Abdulrahman, 2017). The scarcity of standardized carbon auditing and data collection further limits the scope of strong regulation related to climate change (Vimal *et al.*, 2022; Zhu and Geng, 2013).

Lack of collaboration amongst AFSC stakeholders: Each AFSC stakeholder tries to maximize their own profit and hence, avoid expenditure towards the sustainability of the whole network due to lack of collaboration amongst them (Adomako, 2020; Kumar *et al.*, 2023a, b; Mishra *et al.*, 2022; Olatunji *et al.*, 2019; Vimal *et al.*, 2022).

Low investment in green technologies: Climate neutrality initiatives require the use of green technologies however, investment in such technologies is less due to uncertainty over its return on investment (Kumar *et al.*, 2023a, b; Mishra *et al.*, 2022).

Lack of information and education awareness: AFSC stakeholders are not very aware of the leverage associated with climate neutrality and hence, lack the initiative for the same (Kumar *et al.*, 2023a, b; Vimal *et al.*, 2022; Zhu and Geng, 2013). Additionally, information penetration about climate neutrality is quite less amongst the AFSC stakeholders.

Greenwashing risks: Greenwashing practices result in exposing the firms to the risk of misleading their customer and hence, is often criticized (Pinkse and Busch, 2013). The organizations try to initiate climate neutrality practices to improve their image and create differentiation in the market.

Lack of technical knowledge: Climate neutrality initiatives require knowledge of technologies and procedures that are suiting to the environment and lack of such knowledge impedes climate neutrality initiatives (Del Giudice *et al.*, 2021; Mishra *et al.*, 2022; Zhang *et al.*, 2022a).

Lack of infrastructure: Climate neutrality initiatives require physical, technological and information infrastructure however, the Indian AFSC is disintegrated and lacks such infrastructure (Kumar *et al.*, 2021; Mishra *et al.*, 2022; Zhang *et al.*, 2022a).

Bureaucracy in agro-food sector: Bureaucracy increases the complexity of the food system and prevents innovation in the AFSC (Zhang *et al.*, 2022a).

Financial constraint: Finance is a key element in executing critical upgradation required for any new initiative and on a similar line, lack of finance is a hindrance to climate neutrality too (Mishra *et al.*, 2022; Zhu and Geng, 2013). Carbon offsetting requires additional funds. Furthermore, auditing carbon and reporting is a complex procedure that incurs costs in addition to the brokerage fees for buying and selling carbon credit.

Barriers/References	Adomako (2020)	Brander *et al.* (2021)	Cohen and Vandenbergh (2012)	Del Giudice *et al.* (2021)	Koh *et al.* (2023)	Kovak *et al.* (2022)	Kumar *et al.* (2023a, b)	Liu *et al.* (2017)	Mishra *et al.* (2022)	Papadis and Tsatsaronis (2020)	Pinkse and Busch (2013)	Olatunji *et al.* (2019)	Subramanian and Abdulrahman (2017)	Vimal *et al.* (2022)	Yadav *et al.* (2022)	Zhang *et al.* (2022a)	Zhu and Geng (2013)	From this study
Lack of strong policy framework							✓		✓				✓	✓			✓	
Lack of collaboration amongst AFSC stakeholders	✓						✓		✓			✓		✓				
Low investment in green technologies							✓		✓									
Lack of information and education awareness					✓		✓							✓			✓	
Greenwashing risks											✓							
Lack of technical knowledge				✓					✓							✓		
Lack of infrastructure							✓		✓							✓		
Bureaucracy in agro-food sector																✓		
Financial constraint					✓				✓								✓	
Overdependencies on chemical and fertilizers																		✓
Less demand for low carbon products								✓										
Less demand for GMO foods						✓												
The phenomenon of Leakage			✓															
Resistance to change amongst AFSC stakeholders																		✓
Complexity of AFSC structure												✓			✓			
Unclear benefits										✓							✓	
Immaturity of climate-accounting techniques		✓												✓				
High dependency on fossil fuel as energy source																		✓

Source(s): Authors' own work

Table 1. Mapping of climate neutrality barriers in AFSC with existing literature

Parameters	Details	No. of respondents	Proportion of respondents (%)
Questionnaire survey ($N = 42$)			
Qualification	Graduate	19	45.24
	Post-graduate	15	35.71
	Doctorate	8	19.05
Experience	<5 years	7	16.67
	5–10 years	15	35.71
	11–20 years	9	21.43
	>20 years	11	26.19
Position in AFSC sector	Consumer	9	21.43
	Commission agent	3	7.14
	Member of a local farmers producer organization (FPO)	13	30.95
	Project engineer	2	4.76
	Mill owner	2	4.76
	AFSC consultant	6	14.29
	Associate Professor	3	7.14
	Professor	2	4.76
	Chief technical officer	1	2.38
	Chief executing officer	1	2.38
Focus group ($N = 6$)			
Qualification	Post-graduate	4	50
	Doctorate	2	50
Experience	<10 years	3	50
	10–20 years	1	16.67
	>20 years	2	33.33
Position in the AFSC sector	Consumer	1	16.67
	Commission agent	1	16.67
	Vice-president of a local FPO	1	16.67
	Associate Professor	1	16.67
	Chief technical officer	1	16.67
	Chief executing officer	1	16.67

Source(s): Authors' own work

Table 2.
Profile of respondents and focus group participants

Overdependencies on chemical and fertilizers: To meet the ever-growing demand for food items, farmers are overdependent on the use of chemicals and fertilizers for more productivity.

Less demand for low carbon products: Climate neutrality initiatives are not popularized due to willingness amongst the consumer side (Liu *et al.*, 2017). Another reason includes the high cost of such products which doesn't suit to pocket of Indian consumers.

Less demand for genetically modified organism (GMO) foods: GMO crops have the potential to support climate change through lesser agricultural GHG emissions (Kovak *et al.*, 2022) however, less demand for GMOs due to health concerns is a hindrance to climate neutrality.

The phenomenon of Leakage: Policymakers fear that stringent laws in their country will shift the production to another and hence, are not much bothered about GHG reduction (Cohen and Vandenbergh, 2012).

Resistance to change amongst AFSC stakeholders: AFSC stakeholders are habituated to traditional practices and fear that digitization and other modern technology may devalue their status quo and hence, are ignorant towards such developments.

Climate neutrality barriers (CNB)	Average score
Lack of strong policy framework (CNB1)	4.25
Lack of collaboration amongst AFSC partners (CNB2)	3.9
Low investment in green technologies (CNB3)	3.96
Lack of information and education awareness (CNB4)	4.5
Lack of technical knowledge (CNB5)	4.25
Immaturity of climate-accounting techniques (CNB6)	3.66
Lack of infrastructure (CNB7)	4.0
Bureaucracy in agro-food sector (CNB8)	3.66
Financial constraint (CNB9)	4.5
Overdependencies on chemical and fertilizers (CNB10)	3.84
Less demand for GMO foods (CNB11)	3.44
The phenomenon of leakage (CNB12)	3.76
Resistance to change amongst AFSC stakeholders (CNB13)	3.36
Unclear benefits (CNB14)	4.25
High dependency on fossil fuel as energy source (CNB15)	3.72
Greenwashing risks (CNB16)	3.76

Source(s): Authors' own work

Table 3. List of climate neutrality barriers in AFSC

Complexity of AFSC structure: Due to the complex nature of AFSC, traceability becomes extremely difficult to estimate the actual emissions (Olatunji *et al.*, 2019; Yadav *et al.*, 2022).

Unclear benefits: Most of the AFSC stakeholders are not sure about the clear-cut benefits (e.g. economic gain) of climate neutrality and hence, are not very interested (Papadis and Tsatsaronis, 2020; Zhu and Geng, 2013).

Immaturity of climate-accounting techniques: It's difficult to estimate the GHG emissions of all AFSC activities and this leads to distrust amongst stakeholders about climate accounting practices (Brander *et al.*, 2021; Vimal *et al.*, 2022).

High dependency on fossil fuel as energy source: AFSC stakeholders are dependent on heavy machinery and equipment for various activities that require fossil fuels as energy sources. Transportation further increases dependencies on these fuels and harms the environment.

3. Research methodology

The present study was conducted in three phases (Yadav and Majumdar, 2023). In the first phase, the identification of barriers was carried out from the literature using online databases EmeraldInsight, Scopus, Wiley, Web of Science, ScienceDirect, Google Scholar and IEEE Xplore with keywords related to the theme of the present work ("barriers" OR "challenges" OR "hindrances" OR "impediment") AND ("climate neutral" OR "climate neutrality") AND ("agriculture food supply chain" OR "agriculture supply chain" OR "food supply chain"). The result of these searches was evaluated by both the authors and cross-references were also checked. In addition to this, domain experts' opinion (details of domain experts are provided in Table 2) was also taken which resulted in three additional barriers namely overdependencies on chemical and fertilizers, resistance to change amongst AFSC stakeholders and high dependency on fossil fuel as an energy source.

In phase two, a questionnaire was prepared to evaluate the significance of each identified barrier. For this, a 5-point Likert scale was utilized where 1 denotes "not a barrier" and 5 denotes a "very high-intensity barrier". The questionnaire contained 18 items and was circulated to people from the agriculture industry, academia and farmer's community. The questionnaire had a provision for the respondent to make any further suggestions. The obtained responses helped us to shortlist the relevant barriers for further analysis.

Thereafter, a focus group was created to elicit the relationships between the barriers for estimating the structural model based on the WINGS method. WINGS method was chosen as it fits the context of the study and had several advantages over other similar approaches (Govindan *et al.*, 2022; Yadav and Majumdar, 2023). Since the objective was to evaluate the interrelationship between the constructs, methods like "interpretative structure modelling (ISM)", "total interpretative structural modelling (TISM)" and "Decision-making trial and evaluation laboratory (DEMATEL)" are other approaches that can be used. However, ISM and TISM don't provide the intensity of interrelationship and hence, would not be able to answer RQ3 of this work (Yadav and Majumdar, 2023). On the other side, DEMATEL is an approach that creates a structural model through diagraphs and matrices and also provides intensity between the constructs under study. This method also helps in categorizing the construct into cause-and-effect groups but only considers the influence of one construct on other constructs in evaluating the interrelationship. It lacks the consideration of the strength of the construct which in real scenarios along with the influencing power of the construct is a better measure while evaluating interrelationship and intensity amongst them (Michnik, 2013). This limitation of DEMATEL is overcome by the WINGS method which considers the both influence of a construct as well as its inherent strength (Govindan *et al.*, 2022; Michnik, 2013; Yadav and Majumdar, 2023). Hence, the WINGS method was more suitable for this study considering its advantages over ISM, TISM and DEMATEL (Yadav and Majumdar, 2023).

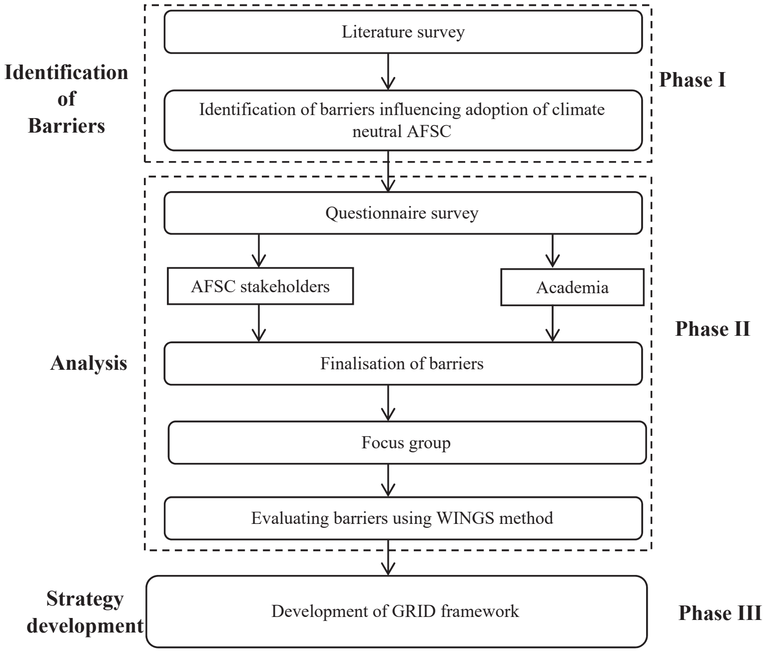
In the third phase, the "green, resilient and inclusive development (GRID)" framework was conceptualized based on the interpretation of results to overcome the identified barriers. The GRID framework was proposed by the World Bank and The World Economic Forum (World Bank, 2021; World Economic Forum, 2022) and has three pillars, i.e. green, resilience and inclusion. Each pillar of the GRID framework has a common objective, i.e. to ensure growth for all, shared prosperity and a sustainable future. As the adoption of climate neutrality in Indian AFSC requires the active inclusion of several stakeholders like farmers, the agriculture industry, government, academia and society hence, the GRID framework was found to be a suitable approach to address the identified barriers. The roadmap of all three phases carried out for this work is shown in Figure 1.

3.1 WINGS method

The WINGS method is given by Michnik (2013). This method considers both the strength and influence intensity to study the interaction effect (Govindan *et al.*, 2022). Michnik (2013) drew an analogy of two physics laws to justify this claim, i.e. the Gravitation law and Coulomb's law. For example, in the case of elastic collision, velocity, as well as colliding masses, contribute to the impact. Similarly, masses (charges) and distance between them contribute to the force magnitude on the two elements (electric charges or masses) (Michnik, 2013). In recent times, the WINGS method has found application in fields like industrial symbiosis (Yadav and Majumdar, 2023), blockchain in healthcare (Govindan *et al.*, 2022), green supply chain (Wang *et al.*, 2021), reverse logistics (Kaviani *et al.*, 2020) and project selection (Michnik, 2018). Hence, the present study utilized the WINGS method to study the barriers to the adoption of climate neutrality in Indian AFSC. The procedure adopted for carrying WINGS method is discussed as follows:

1. Identification of constructs: At first, the construct under study was identified through a suitable approach. This study made use of a literature review, expert opinion and questionnaire survey to finalize the constructs.

2. Estimation of a causal relationship: The causal relationship graph was utilized to evaluate the interdependencies (Michnik, 2013).



Source(s): Authors' own work

Figure 1.
Research framework

3. Determination of the strength and influence intensities: For this, verbal expression ["no (N) – 0; very low (VL) – 1; low (L) – 2; high (H) – 3; very high (VH) – 4"] was utilized to indicate the strength of construct and its influencing intensity with another construct.
4. Determination of "average direct strength-influence matrix (A)": A matrix with elements as a_{mn} was computed where the construct's strength component was taken in the diagonal of the matrix, whereas the influence intensity of "construct 1" on "construct 2" was filled in the row (m) and column (n) of the matrix a_{mn}. All experts filled in these data and their responses were averaged to get the matrix A. In the case of a focus group, averaging was not required if the group reached a consensus.
5. Computation of normalized matrix: The matrix A was normalized by using equation (1).

$$B = \frac{A}{k} \tag{1}$$

$$where\, k = \sum_{m=1}^{p} \sum_{n=1}^{p} a_{mn}$$

B is the normalized matrix. p is the number of experts. However, this study used a focus group-based approach where experts reached a consensus on a single value, and hence, the value of p is equal to unity in this work.

6. Computation of "total strength-influence matrix (T)": This matrix with elements as t_{mn} was computed using Equation (2).

$$T = \frac{B}{I - B} \tag{2}$$

Here, I is the identity matrix with a dimension equal to the number of constructs considered in the study.

7. Calculation of indicator's score: Total impact (i_m) and total receptivity (r_n) were computed through Equations (3) and (4), respectively. This was followed by the construct's ranking based on the indicators i_m, r_n, $(i_m + r_n)$ and $(i_m - r_n)$. $(i_m + r_n)$ and $(i_m - r_n)$ was called total engagement and role, respectively.

$$i_m = \sum_{n=1}^{p} t_{mn} \tag{3}$$

$$r_n = \sum_{m=1}^{p} t_{mn} \tag{4}$$

4. Data analysis

The research framework shown in Figure 1 was followed. A questionnaire was prepared and sent to 109 individuals related to climate neutrality and stakeholders of the Indian AFSC. The respondents of the survey were identified by convenient sampling through the connection of the authors. One of the authors comes from a farming family background and the other author had several years of consultancy experience with agro-food industries. This helped to reach out to the initial stakeholders. The survey was floated through personal email, social media platforms (LinkedIn) and personal messaging apps (WhatsApp). Despite these, only 42 individuals responded and their profile is shown in Table 2. The response rate of the questionnaire survey was 38.53% which can be considered as low. However, Nulty (2008) summarized the average response rate of various online surveys and found that it was 33%. Thus, the response rate of the survey was in the acceptable range. Another important aspect of the survey was taking care of non-response bias. Non-response bias exists when the characteristics of respondents who refuse to participate or leave the survey in between differ from those who do participate in the survey, leading to biased results. Thus, the responses for non-response bias were also checked. For this, the first 21 responses (50%) were compared with the last 21 responses (50%), and no significant difference was observed which shows that non-response bias is not a concern for this study. In general, when questions are clearly understood by the respondents; the chances of leaving the survey in between is very low. This was ensured by showing the questions to five executive postgraduate students having experience of working with agro-food industries and the changes suggested by them were well incorporated to increase the readability of the survey. The criticality of the barrier was obtained on the scale of five-point Likert scale rather than the seven-point Likert scale. It was done to simplify the options for respondents since the criticality is measured on the arithmetic mean where both scales will have a similar trend because lower will remain lower while upper will remain upper in both scales. In the literature for assessment of barriers, researchers like Bag *et al.* (2022) and Roy *et al.* (2022) in their recent study have used a 5-point Likert scale while Shanmugasegaram *et al.* (2012) have validated the 5-point Likert scale for barriers assessment. The obtained result from the questionnaire survey showed that the average score for 16 barriers was above three (threshold value for this work) out of five while for the other two it was below three and hence, these two were eliminated from further analysis (shown in Table 3).

Thereafter, a focus group of six experts was constituted and their profile is shown in Table 2. Focus group as a method for an open-ended discussion among the domain experts was necessary to understand the underlying complexity of influence–strength relationships between the barriers. Besides, in case of conflicting opinions arising from different experts, consensus was reached easily through deliberation. The focus group domain experts have rich experience in the Indian AFSC sector and academia. To obtain influence and strength, a meeting was conducted with the focus group via online mode on the Zoom platform. The influence and strength of each identified barrier were discussed in depth until a consensus was reached amongst the experts. This resulted in obtaining the "average direct influence strength matrix (A)" as discussed in step 4 of the WINGS methodology in section 3. Furthermore, the obtained matrix was subjected to Equation (1), and the normalized influence strength matrix was computed. Thereafter, Equation (2) was utilized to get the total strength influence matrix which is shown in Table 4. Table 4 also shows the total impact and total receptivity of a particular barrier obtained through Equations (3) and (4) respectively. The meeting lasted for two hours and fifteen minutes which included one scheduled break of fifteen minutes. The session was moderated by the first author. The recording of the session was provided to the focus group participants along with an analysis so that they could suggest the mitigation strategy. Additionally, it was also requested if any of the participants were concerned about the obtained results; the same could be discussed again. However, no objections were reported which further motivated us to carry next phase of the study about the mitigation strategy.

5. Results and discussions

5.1 Cause-group and effect-group barriers

This section answers *RQ1*. Table 5 shows the ranking of climate neutrality barriers based on different indicators. The engagement score (i.e. the sum of total impact and receptivity) represents the importance of a barrier and the role score (i.e. the difference of total impact and receptivity) depicts the influencing capacity of a barrier with respect to the other barriers. A positive value of the role score for a barrier indicates that it belongs to the cause group and a negative value implies that it belongs to the effect group. Based on this, nine barriers were categorized into the cause group, and the other seven barriers were categorized into the effect group. Low investment in green technologies (CNB3), resistance to change amongst AFSC stakeholders (CNB13), lack of strong policy framework (CNB1), lack of collaboration amongst AFSC stakeholders (CNB2), lack of information and education awareness (CNB4) and lack of technical expertise (CNB5) were found to be the top five barriers in terms of total engagement (i.e. strength). Here, six barriers are mentioned in the ranking since CNB4 and CNB5 jointly hold the rank 5 due to the same score. Likewise, financial constraint (CNB9), lack of information and education awareness (CNB4), lack of technical expertise (CNB5), bureaucracy in agro-food sector (CNB8) and lack of infrastructure (CNB7) were the top five barriers in terms of role (i.e. influence). One interesting instance was observed that CNB2, CNB4 and CNB5 obtained a higher rank (amongst the top five) in three indicators. Similarly, the other three barriers namely, CNB1, CNB3 and CNB13 were ranked higher in two indicators. Hence, these six barriers require extra attention and suitable mitigating strategies should be adopted to eliminate them first.

5.2 Relationships among the barriers

To address the *RQ2* about the inter-relationship between the identified barriers, an influence-relation map was drawn. For this purpose, a threshold value was estimated by the "average of matrix T + standard deviation of matrix T". Furthermore, this threshold value was utilized to

Table 4. Total strength-influence matrix of climate neutrality barriers

	CNB1	CNB2	CNB3	CNB4	CNB5	CNB6	CNB7	CNB8	CNB9	CNB10	CNB11	CNB12	CNB13	CNB14	CNB15	CNB16	Total impact (i_m)
CNB1	*0.0096*	*0.0073*	*0.0096*	0.0049	0.0049	0.0050	*0.0072*	0.0025	*0.0071*	0.0025	0.0025	*0.0073*	0.0050	0.0027	0.0025	0.0050	0.0856
CNB2	0.0049	*0.0072*	*0.0073*	0.0049	0.0049	*0.0073*	0.0049	0.0025	0.0048	0.0025	0.0048	0.0050	*0.0073*	0.0026	0.0048	*0.0072*	0.0828
CNB3	0.0026	0.0049	*0.0073*	*0.0072*	*0.0072*	*0.0095*	0.0048	0.0048	0.0025	0.0048	0.0048	0.0050	0.0050	0.0027	0.0001	0.0049	0.0780
CNB4	0.0050	*0.0096*	0.0051	0.0049	0.0049	*0.0072*	0.0049	*0.0071*	0.0003	0.0048	*0.0071*	*0.0096*	*0.0074*	*0.0073*	0.0002	0.0050	0.0903
CNB5	0.0050	0.0050	*0.0073*	0.0049	*0.0072*	*0.0095*	0.0049	0.0048	0.0002	0.0025	0.0048	*0.0073*	*0.0074*	*0.0095*	0.0025	0.0050	0.0878
CNB6	0.0025	0.0048	0.0025	0.0024	0.0025	0.0048	0.0001	0.0001	0.0001	0.0001	0.0024	0.0025	0.0048	0.0047	0.0001	*0.0070*	0.0415
CNB7	*0.0072*	*0.0073*	0.0050	*0.0072*	0.0049	*0.0072*	*0.0071*	0.0002	0.0002	0.0002	0.0002	0.0050	*0.0073*	*0.0072*	0.0048	0.0050	0.0758
CNB8	*0.0072*	0.0049	*0.0072*	0.0049	0.0003	0.0003	*0.0071*	0.0025	*0.0071*	0.0025	0.0001	*0.0072*	0.0049	0.0026	0.0001	0.0026	0.0614
CNB9	*0.0072*	0.0050	*0.0096*	0.0049	0.0049	*0.0073*	*0.0095*	0.0048	*0.0094*	0.0025	0.0002	0.0027	0.0027	0.0049	0.0001	0.0003	0.0760
CNB10	0.0002	0.0002	0.0002	0.0001	0.0001	0.0024	0.0024	0.0024	0.0047	*0.0070*	0.0000	0.0047	0.0048	0.0024	0.0024	*0.0070*	0.0411
CNB11	0.0025	0.0002	0.0048	0.0048	0.0025	0.0025	0.0001	0.0024	0.0001	0.0001	0.0047	0.0048	*0.0071*	0.0048	0.0001	0.0048	0.0464
CNB12	*0.0072*	0.0026	*0.0073*	0.0048	0.0049	0.0026	0.0003	0.0025	0.0048	0.0025	0.0002	0.0049	*0.0072*	*0.0071*	0.0001	*0.0071*	0.0662
CNB13	0.0049	*0.0072*	0.0050	0.0049	0.0049	0.0026	0.0048	0.0025	0.0025	0.0025	0.0048	*0.0072*	0.0050	*0.0072*	0.0048	0.0049	0.0757
CNB14	*0.0072*	*0.0072*	*0.0073*	0.0026	0.0026	0.0027	0.0049	0.0025	0.0048	0.0048	0.0048	*0.0073*	*0.0096*	0.0049	0.0025	0.0050	0.0806
CNB15	0.0001	0.0001	0.0001	0.0001	*0.0070*	0.0001	0.0001	0.0024	0.0000	0.0001	0.0000	0.0001	0.0024	0.0001	*0.0093*	*0.0070*	0.0289
CNB16	0.0025	0.0048	0.0048	0.0025	0.0048	*0.0071*	0.0002	0.0047	0.0001	0.0047	0.0001	0.0025	0.0025	0.0025	0.0047	0.0026	0.0510
Total receptivity (r_n)	0.0757	0.0784	0.0904	0.0660	0.0684	0.0783	0.0633	0.0487	0.0486	0.0439	0.0416	0.0830	0.0902	0.0732	0.0389	0.0804	$\lambda =$ *0.0068*

Note(s): λ = *threshold value for significant relationship = average of matrix T + standard deviation*
Source(s): Authors' own work

Climate neutrality barriers (CNB)	Total impact (i_m)	Total receptivity (r_n)	Total engagement ($i_m + r_n$)	Role ($i_m - r_n$)	Group
Lack of strong policy framework (CNB1)	3	6	3	6	Cause
Lack of collaboration amongst AFSC stakeholders (CNB2)	4	4	4	9	Cause
Low investment in green technologies (CNB3)	6	1	1	12	Effect
Lack of information and education awareness (CNB4)	1	9	5	2	Cause
Lack of technical expertise (CNB5)	2	8	5	3	Cause
Immaturity of climate-accounting techniques (CNB6)	14	5	11	16	Effect
Lack of infrastructure (CNB7)	8	10	8	5	Cause
Bureaucracy in agro-food sector (CNB8)	11	11	12	4	Cause
Lack of finance (CNB9)	7	12	10	1	Cause
Overdependencies on chemical and fertilizers (CNB10)	15	13	14	10	Effect
Less demand for GMO foods (CNB11)	13	14	13	8	Cause
The phenomenon of leakage (CNB12)	10	3	7	14	Effect
Resistance to change amongst AFSC stakeholders (CNB13)	9	2	2	13	Effect
Unclear benefits (CNB14)	5	7	6	7	Cause
High dependency on fossil fuel as energy source (CNB15)	16	15	15	11	Effect
Greenwashing risks (CNB16)	12	7	9	15	Effect

Source(s): Authors' own work

Table 5. Ranking of climate neutrality barriers

show the significant relationship hence, any value in Table 4 that was greater than this threshold value was considered to have a significant influential relationship. For better picturization, the same was highlighted in italic letters (refer to Table 4). This information was used to draw an influence-relation map (Figure 2) which showed that lack of information and education awareness (CNB4), lack of infrastructure (CNB7), lack of technical expertise (CNB5), lack of strong policy framework (CNB1) and unclear benefits (CNB14) are the most significant barriers influencing several other barriers. This is evident and in agreement with the role score ranking of barriers (2, 5, 3, 6 and 7 respectively).

Lack of information and education awareness (CNB4) is influencing other seven barriers, namely CNB2, CNB6, CNB8, CNB11, CNB12, CNB13 and CNB14. It is observed that AFSC stakeholders try to maximize their profit and thus, this leads to a lack of collaboration amongst AFSC stakeholders. However, the literature showed that joint decisions on inventory are more profitable (Sahare *et al.*, 2021). Additionally, collaboration helps understand the GHG emission at different stages of AFSC. Information asymmetry also increases the complexity at the bureaucratic level. GMO food can reduce GHG emissions however, there exist misconceptions and concerns about its effect on health which further lead to less demand for GMO foods. Another ill effect of limited educational awareness is observed in the lack of willpower to make strong policy decisions as the concerned authorities feel that stringent laws will result in less production leading to a demand shift. Furthermore,

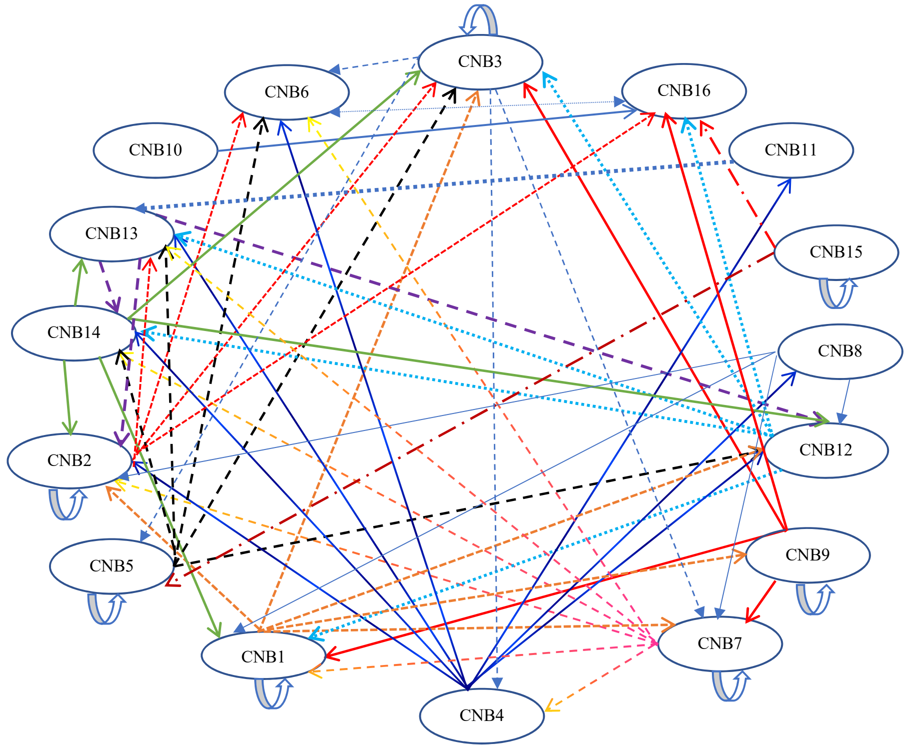


Figure 2. Influence map of climate neutrality barriers

Source(s): Authors' own work

due to the unclear benefits of climate neutrality initiatives, resistance is observed from AFSC stakeholders and lack of information and education awareness is a prime reason for this. Lack of infrastructure (CNB7) is influencing the other six barriers, namely CNB1, CNB2, CNB4, CNB6, CNB13 and CNB14. Climate neutrality initiatives require technological infrastructure through which real-time monitoring is possible. For example, precision agriculture uses data analytics to suggest the optimal amount of water and fertilizers based on the health of the soil. Similarly, a lack of proper infrastructure at warehouses and in the transportation of agricultural produce would lead to more food waste (Magalhães *et al.*, 2021). Under such circumstances, coordination amongst AFSC stakeholder becomes difficult as well and imposing strict policy further worsen the situation. Additionally, this leads to information asymmetry amongst AFSC stakeholders. Since, the Indian AFSC is disintegrated and lacks infrastructure (Yadav *et al.*, 2022), the benefits of climate neutrality initiatives are not visible and hence, the excitement about such efforts is low amongst AFSC stakeholders.

The lack of strong policy framework (CNB1) is influencing the other five barriers namely, CNB2, CNB3, CNB7, CNB9 and CNB12. Unless the government imposes strict regulations about climate neutrality, the concept of net-zero is a mere dream. The policymakers need to bring different AFSC stakeholders on a similar page and need to establish coordination for taking joint initiatives for climate neutrality. Additionally, the policies have long-term strategic vision and hence, affect the decisions like investment in green technologies and infrastructure for a better and sustainable future. Moreover, policymakers need to be ready to take stringent decisions that might have short-term negative repercussions. Lack of technical expertise (CNB5) is influencing the other five barriers namely, CNB3, CNB6, CNB12, CNB13 and CNB14. Lack of technical expertise leads to difficulty in estimating the global warming potential of various AFSC activities and this further adds the complexity in allocating the responsibilities of mitigating strategies for each AFSC stakeholder. Farmers may resist prohibition on stubble burning and may reject other high-end technical solutions due to a lack of technical knowledge. This may influence the investment decision in green technologies if they lack ease of use for farmers.

Unclear benefits (CNB14) is influencing five other barriers namely, CNB1, CNB2, CNB3, CNB12 and CNB13. The leverage associated with climate neutrality is a little vague and is not directly connected with economic gain hence, AFSC stakeholders hesitate to take up such initiatives. Additionally, these unclear benefits limit the investment in green technologies and collaboration among the stakeholders. Due to these reasons, regulation for climate neutrality is not strictly enforced. Furthermore, lack of collaboration amongst AFSC stakeholders (CNB2), bureaucracy in agro-food sector (CNB8), financial constraint (CNB9), the phenomenon of leakage (CNB12) and resistance to change amongst AFSC stakeholders (CNB13) is influencing four barriers each. Low investment in green technologies (CNB3) and high dependency on fossil fuel as an energy source (CNB15) are influencing three and two barriers respectively while CNB6, CNB10, CNB11 and CNB16 are influencing one barrier each.

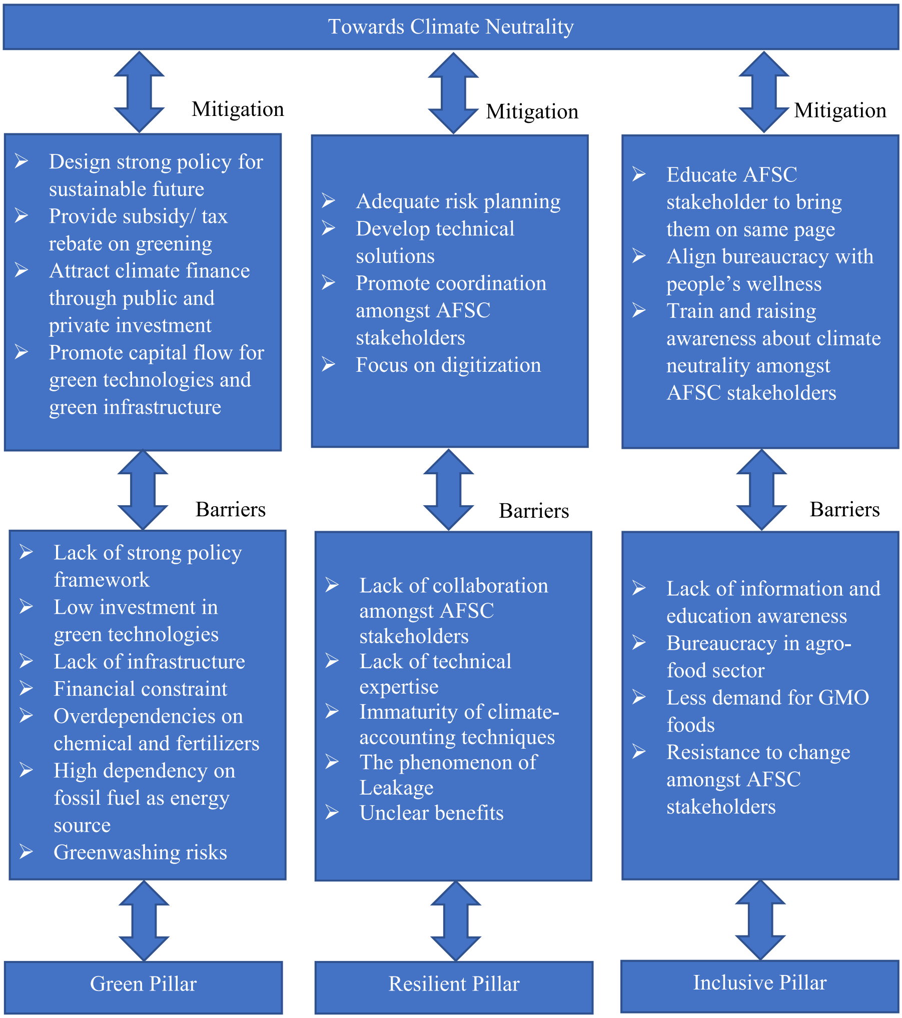
Low investment in green technologies (CNB3), immaturity of climate-accounting techniques (CNB6) and resistance to change from AFSC stakeholders (CNB13) are the most receptive barriers. The total engagement score of CNB3 and CNB13 is very high (ranked 1 and 2). Climate neutrality is severely impacted due to low investment in green technologies and hence, is driven by most of the cause-group barriers. Additionally, due to the nature of the Indian AFSC, climate accounting is very complex and hence, is influenced by many other barriers identified in this work. At last, the Indian AFSC is strongly linked to the traditional approach of operations and is quite hesitant about any upgradation.

6. Strategy development using the GRID framework

This section addresses *RQ3*. An in-depth discussion was carried out again with the focus group to propose a portfolio of strategies for addressing the identified barriers in general while special attention was paid to the cause-group barriers. For this, the focus group had the consensus to use the GRID framework for the same. This meeting was also conducted online on the Zoom platform. The meeting lasted for five and a half hours with three scheduled breaks of fifteen minutes each. The discussion of the meeting was summarized in the form of a GRID framework. At first, the identified barriers were mapped (which could be seen in the barriers block in Figure 3) with respect to the three pillars of the GRID framework. Thereafter, strategies were devised for each barrier and are mentioned under the mitigation block in Figure 3.

6.1 GRID framework

GRID framework has three pillars namely, green, resilient and inclusive (Mukherjee *et al.*, 2023). These three pillars are utilized to suggest mitigating strategies for the identified barriers. Furthermore, the suggested strategies would be helpful to AFSC stakeholders in understanding their future course of action to combat climate neutrality. This framework caters to the need for economic development and environmental goals along with inclusion. The conceptualization of the GRID framework in mitigating the climate neutrality barriers is depicted in Figure 3. Moreover, a description of each pillar and mitigating strategies are mentioned in the subsequent subsection.



Source(s): Authors' own work

Figure 3.
GRID framework for mitigating climate neutrality barriers

6.1.1 Green pillar. The green pillar focuses on a sustainable future where socio-economic, environmental and financial sustainability are core concerns. To achieve this goal, focus group participants were in favour of designing strong policies and enforcement of formulated regulations which require strong political will power. This addresses the barriers related to the lack of a strong policy framework and greenwashing risks. Additionally, climate financing came out to be an important aspect in the discussion which should be attracted through public and private investment considering future growth and efforts that need to be taken towards activities that challenge sustainable development (Zhang *et al.*, 2022b). Investment in clean products will offer several benefits at the international level in terms of demand and increasing market share. Apart from this, subsidy and tax rebate benefits should be promoted by the government. Furthermore, the investment should be diverted towards developing green technologies and green infrastructure. Thus, climate financing, investment in clean product, and providing subsidy and rebates addresses the barriers related to low investment, infrastructure, finance, and overdependence on fertilizers and chemicals.

Four out of six focus group participants were in support of advocating organic farming since it supports climate neutrality initiatives by reducing agricultural GHG emissions and hence, such approaches should be promoted amongst the AFSC stakeholders for sustainable production and consumption. However, two focus group participants were suspicious about the economic viability of organic farming. The pros and cons of organic farming were discussed at length and the example of organic farming Indian state of Sikkim made everyone convinced that it is the right approach for the climate neutrality initiative. Hydrogen as a fuel has significant potential in decarbonizing various industries such as fertilizers which will reduce substantial reduction in GHG emissions. It is estimated in one of the McKinsey reports that more than 20% of total yearly global emission reduction by 2050 (McKinsey, 2020).

6.1.2 Resilient pillar. The resilient pillar focuses on mitigating any risk arising either due to natural or man-made hazards as well as ecotechnological and social shocks. This encourages countries, governments and firms to come together and take the initiative to invest in risk management for events like financial shocks, recessions, natural hazards, conflict and violence, climate change and pandemics driven by zoonotic diseases. Finance should be diverted in such a way that it should support a green portfolio. Additionally, there is a need to develop technologies that promote resilient and sustainable agriculture (Yadav *et al.*, 2022). Along with this, consumer support is of utmost importance, and sustainable consumer behaviour is expected from society. Moreover, to make the AFSC resilient, there is a dire need for newer business models, diffusion of technologies solutions and application of green emerging technologies (Nayal *et al.*, 2023). According to a study by the University of Melbourne, technology alone can reduce 80% reduction in methane emissions due to livestock production and 50–60% reduction in the use of fertilizers (http://tinyurl.com/bdh8wkry). Thus, focusing on risk planning, technical expertise, coordination and digitization will address the barriers related to collaboration, technical glitch, accounting process of GHG emissions and brings transparency across AFSC.

6.1.3 Inclusion pillar. The inclusive pillar focuses on reducing the increasing inequality and disparity between different social groups. For example, the middlemen eat the major chunk of the profit in Indian AFSC which creates a sense of resistance amongst the farmers and hence, such malpractices need to be avoided to promote harmony among the stakeholders (Yadav *et al.*, 2022). The inclusive pillar brings a human-centric approach and aims to provide an equal platform for everyone to grow together. In a nutshell, the inclusive pillar of the GRID framework promotes equity among all. For this, awareness programs about climate neutrality and one's contribution should be pledged like not to waste food and hence, AFSC stakeholders should be educated about the climate neutrality initiatives. One example could be shifting to a greener diet and plant-based protein. The bureaucracy needs to align the government's schemes towards the people's wellness (Zhang *et al.*, 2022a). Funding should be utilized to incentivize environment-friendly efforts. Thus, educating consumers could address the barriers related to lack of information, resistance to climate neutrality efforts and lack of demand for GMO foods.

6.2 Implications of the research

Implications for farmers: Farmers should meet their electricity demand from renewable sources. Solar pumps could be utilized for irrigation while solar panels could be useful for other electricity needs. FPO could be a potential facilitator to aggregate the produce after harvesting which leads to the optimization of transportation and logistics costs. This will also help the farmers to make a profit by minimizing their supply chain costs. Organic farming is another area where farmers could leverage significant gains from the subsidy by the government and even enjoy a superior price for their produce. Technology is an enabler for climate neutrality initiatives which could be leveraged to make insightful decisions. Remote sensing and precision agriculture could be helpful in the context of smart farming to optimize the available resources. Innovative methods such as direct seeding rice should be promoted which reduces both the cultivation cost and requires less water for irrigation. It also reduces sowing time, labour and the need for chemical herbicides and fertilizers leading to less nitrous oxide emission. In addition to this, not tilling the soil reduces the methane emissions.

Implications for agro-food industries: The agro-industries should start their climate neutrality journey by estimating the global warming potential of associated activities along the supply chain. This step includes measuring and communicating GHGs and carrying out the life cycle assessment. For this, help from India GHG Program may be considered which is a voluntary initiative for managing and measurement of GHG emissions in India. This initiative was launched by the Confederation of Indian Industry (CII), WRI India and The Energy and Resources Institute (TERI) in March 2012. Thereafter, planning needs to be carried out for reducing the GHGs, and subsequently, a target could be decided. Following this, insetting (within) and offsetting (outside) of GHG emissions is to be done to achieve climate neutrality which further requires certification and verification through independent parties. For example, Sikkim is the first state in India to get certification for organic farming. At last, climate labelling may be obtained to leverage the initiative undertaken. This will further motivate others to take similar climate neutrality initiatives and create awareness amongst the stakeholders about climate change.

Implications for consumers: Consumers are important stakeholders in AFSC and could play a significant role in the climate neutrality journey. The awareness in consumers about climate neutrality could lead to changing dietary preferences in terms of reduction in animal meat consumption and shifting towards plant protein-based sources. Consumers starting small initiatives for reducing food wastage will have a greater impact on the whole food chain network. Additionally, pressure from consumers for sustainable food will force other stakeholders of AFSC to align their efforts toward cleaner production, processing and transportation of food items.

Implications for policymakers: In India, agriculture is classified under a concurrent list where most of the policies and control are exercised by the state governments while few of the agriculture-related items are under the control of the Union government. The government should run a campaign to create awareness of carbon neutrality initiatives. To reduce GHG emissions, the development of infrastructure is a must, e.g. rail transport produces fewer GHGs than that of road and air modes. The availability of renewable sources of energy would decrease the farmer’s dependency on coal-based electricity. Additionally, the government should provide subsidies and tax rebates on agriculture equipment, renewable energy infrastructure such as solar panels, and solar pumps, establishing biogas plants, etc. Organic farming and sustainable initiatives should be promoted and marketed by government agencies so that more farmers are motivated to take up these activities. The State of Kerala in India has successfully tested 170 tons of carbon negative in its Aluva seed farm. Training is another aspect where the government has to work to enhance the digital readiness of various stakeholders for climate neutrality initiatives.

Implications for academics and research: The present work identifies and models the climate neutrality barriers in the Indian AFSC. On the methodological aspects, the work is benefitted from the integrated WING-GRID framework where the WINGS method evaluated the intensity of each barrier not only based on the influence but also on considering the strength of each barrier while the GRID framework is utilized to suggest the strategies to overcome the identified barriers of climate neutrality in Indian AFSC. The findings of this research have significant academic and research implications as the barriers to climate neutrality have been categorized into cause-group and effect-group. Wherever complex interrelationship is observed amongst a large number of barriers, clarity in terms of "critical few and trivial many" arises. This issue is addressed in this work by ranking the barriers in terms of "role score" and subsequently making the influence map. The policymakers, AFSC stakeholders and concerned authorities in AFSC will thus get a clear picture of the causal barrier and hence, can take prompt action to address them immediately. Therefore, the present work research will be helpful for the agriculture sector, policymakers, government, regulatory bodies and AFSC stakeholders to make the way for climate neutrality.

7. Conclusion, limitations and future work

Climate change has disturbed the natural ecosystem as well as threatened the food supply chain and hence, global efforts are required to address this burning issue. Several countries have pledged to achieve net-zero in the next few decades. However, there exist various roadblocks to achieve the same, and sector-wise obstacles are also observed. In this context, the present work identifies and models the barriers to climate neutrality in the Indian AFSC. This knowledge could be utilized by AFSC stakeholders for their preparedness for climate neutrality. Furthermore, the interrelationship between barriers is modelled using the WINGS method which considers both the strength (internal importance or power of a construct) and influence (affecting the intensity of a construct). The obtained results reveal that financial constraint (CNB9), lack of information and education awareness (CNB4), lack of technical expertise (CNB5), bureaucracy in the agro-food sector (CNB8) and lack of infrastructure (CNB7) are the most significant cause group barriers in achieving climate neutrality in Indian AFSC. Hence, these barriers require the maximum focus, and subsequent mitigation strategies should be undertaken. Moreover, to address the identified barriers, the present work also proposes the application of the GRID framework. This framework advocates strategies that are aligned with green, resilient and inclusive aspects of development. In a nutshell, WINGS is utilized to understand the interrelations and intensity of interrelationships between identified barriers, while the GRID framework is used to suggest the strategy to eliminate the barriers of climate neutrality in Indian AFSC. The present study also proposes some suggestions for the Indian AFSC to take climate neutrality initiatives. A few important ones include leveraging climate financing, regulation for sustainable agriculture, investment in green technologies, training of AFSC stakeholders for using technology and creating awareness to practice sustainability along the whole value chain. Indian Government is also trying at their level to initiate and motivate the farmers to take up climate neutrality initiatives, e.g. the Indian Government amended the "Energy Conservation Act, 2001" paving the way for starting carbon trading companies. This act will allow setting up carbon farming and selling the carbon credits associated with farms leading to increased income for farmers.

The limitations of the present work include lack of employing statistical method to compare the search results for enlisting the barriers from the literature. Another limitation is about its geographical context and macroscopic view. However, with few alterations the results of the study can be utilized for other developing countries and more specifically South Asian countries since they have a lot of similarities with India. Additionally, this work considers the entire AFSC as a single entity. However, AFSC has several stages including farming, distribution, storage, food processing and so on with different technology penetration at each stage. Therefore, a microscopic study that focuses on different stages of AFSC will yield more accurate and useful findings. Future research may explore the role of technology and innovation in addressing the identified barriers or examining the effectiveness of different policy interventions in promoting climate neutrality in the agriculture sector.

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