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Full Length Article

Benchmark-based prioritizing sustainable consumption and production practices for achieving SDG 12 in India: A multi-criteria decision-making approach

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ABSTRACT

This study prioritizes sustainable consumption and production (SCP) practices to advance SDG 12 in India by employing a hybrid Grey Delphi–Grey DEMATEL framework. Twelve SCP practices identified through a comprehensive literature review were assessed by ten sustainability experts, with Grey Delphi confirming their relevance and Grey DEMATEL mapping the causal structure and influence dynamics within the system. The results show that circular economy practices, multi-stakeholder partnerships, and life cycle assessment function as core driving practices that exert substantial influence on the broader SCP landscape, while sustainable supply chain management, consumption education, urban planning, and green procurement appear as dependent practices shaped by these drivers. By integrating expert judgment and uncertainty-aware analytical techniques, the study provides a structured and replicable decision-support approach that assists policymakers, industry stakeholders, and practitioners in prioritizing impactful SCP interventions tailored to India's socio-economic context, thereby supporting more effective progress toward sustainable development.

1. Introduction

Sustainable Consumption and Production (SCP) has evolved as a highly critical concentration area for sustainable development, particularly in those economies that are increasing rapidly, such as India's. The United Nations has Sustainable Development Goal 12 (SDG 12), which specifies the proper "sustainable consumption and production patterns" [1]. To the Indian nation facing resource depletion, environmental degradation, and socioeconomic challenges, SCP is critical in balancing economic growth with environmental and social sustainability [2]. Especially in India, the second most populous country in the world, with a growing middle class whose consumption and production systems have ramifications for resource use and impacts on the environment at a global level [3], there has been an increasingly focused application and realization of best practices of SCP for achieving the SDG 12 for India while making its contribution to broader sustainable development goals.

SCP is highly relevant for the sustainable development of India. According to Goyal et al. [4], traditional production and consumption systems have been identified as the main causes of environmental degradation and the rapid depletion of natural resources in developing economies such as India. A strategic transition toward sustainability can help achieve several goals, including resource efficiency, waste reduction, pollution mitigation, and social equity [5]. Approaches to SCP can, in turn, open newer avenues towards innovating, increasing competition, and opening new job opportunities in emerging green sectors [6]. India indeed has opened up ambitious development and economic growth, but she needs to put SCP principles into practice accordingly within major sectors and domains of consumption.

Even though SCPs have been considered important, their implementation in India faces tremendous obstacles and challenges. Several studies reported a lack of awareness, financial constraints, technological limitations, regulatory gaps, and aversion to new changes as some of the obstacles among producers and consumers [7,8]. They are also compounded by the complexity and interrelation of the consumption and the production systems, with consequent difficulty in prioritization and practical application of interventions [9]. Against these, there is a pressing need for research studies to be conducted that could

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significantly assist in identifying, assessing, and prioritizing those SCP practices that would be most pertinent and impactful for the Indian scenario. In lieu of this, the current research attempts to fill this bridging gap by giving the SCPs the utmost importance in fulfilling SDG 12 in India using a systematic methodology. The research will shed light on valuable literature and employ sound analytical methods to provide inputs for policymakers, businesses, and other stakeholders to promote SCPs in India. This will introduce a more comprehensive understanding of what practices may need utmost importance and how the adoption hurdles can be intercepted and minimized. The end intention of this research is to add to efforts put in place by India to achieve SDG 12 and achieve its overall success in sustainable development.

2. Literature review

2.1. Current state and challenges of sustainable consumption and production

SCP is a focal point of SDG 12 to "ensure sustainable consumption and production patterns" [1]. SCP practices, when implemented in India, are confronted with multiple challenges. Sharma et al. [2] noted organizational barriers as SCP's foremost hurdle for deploying digital technologies within the supply chain for SCP. Comparable to Goyal et al. [4], it can be noted from the paper that government-linked, management-linked, and finance-linked barriers constitute the core of SCP's hurdles for adoption within Indian manufacturing. These are representative indicators of multiple dimensions of bringing SCP to India, and a multiple-faceted approach is needed to work through several hurdles to be implemented. Luthra et al. [7] elaborated more on these barriers when they specified 15 particular hiccups of SCP adoption within the supply chain for which government support and policies were the most pivotal. Challenges are hardly Indian-specific; Liu et al. [10] found identical barriers even within China, where weakly enforced environmental laws and poor environmental education were some of the key issues. This suggests that developing countries have a unifying challenge of establishing SCP practices and thus need shared knowledge and collaboration.

A lack of awareness and inadequate policy frameworks characterize the current state of SCP in India. According to Mensah et al. [11], the SDG 12 targets are insufficient for monitoring sustainable food consumption, requiring enhanced policy indicators. Abbas et al. [12], in the Indian context, have focused on the importance of eco-labeling and green advertising for achieving SDG 12. The strategies influence consumer perceptions and attitudes toward environmentally friendly products. However, price sensitivity remains a significant challenge that needs to be addressed to promote sustainable consumption patterns in India. It risks what Gladkova calls the "miscommunication of harms," meaning that when communicating accomplishments of such a project, harm through environmental degradation and damage to people's livelihoods goes unrecognized [13]; this can be applicable when considering the implementation process for SDG 12 regarding India. Historically, economic growth has generally been rapid but in tension with sustainability. Stevens, in 2010, said that SCP approaches needed to be more holistic, as sustainable consumption initiatives need to be reconciled with policies that would enhance the private sector's sustainability of production.

The absence of sustainable production practices remains a challenge in several Indian sectors in reaching SDG 12. Shaikh et al. [3] maintain that responsible consumption and production will be achieved when the agri-food system addresses its national cropland limits. Luthra et al. [7] identified 15 barriers to SCP adoption in the Indian manufacturing sector, including government support and essential policies. These studies also highlight the need for a sector-specific approach to help India ensure sustainable production methods. Chiou et al. [14] presented bi-level programming models for sustainable intercity passenger transport systems that could potentially be used in the booming transportation sector of India. Bocean [15] noted that using digital technologies to make the supply chain more sustainable is an area through which the production practices of India's industries could be improved.

The country's rapid urbanization and economic development have created further complexities in implementing the SCP practices in India. Summerhayes et al. [16] emphasized that food diversity and urban environments should be accessible to create sustainable consumption. This requirement in an Indian context for urban planning calls for it to provide for consumption with sustainable consumption patterns. In addition, Carlsen [17] found waste generation to be a pertinent issue in achieving SDG 12 for India's growing urban centers. Han et al. [18] studied the balance between urbanization, economy, and eco-environment in Chinese cities, and their findings can be informative for India's urban development process. Skare et al. [19] identified important synergies and trade-offs between several SDGs, which warrants an integrated approach to urban development to consider the simultaneous implementation of multiple SDGs in India.

Nevertheless, despite the mentioned difficulties, there is still an opportunity for India to make a step ahead toward the achievement of SDG 12. A virtual community platform for promoting responsible consumption and production has been suggested by Whitaker and Pawar [20] that can be adapted to suit the Indian scenario. In addition, Cosentino et al. [21] discussed the fast-growing bio-based construction materials' potential for accelerating the achievement of SDG 12. There is a promising route in sustainable production in the rapidly growing Indian construction sector. Bianchet et al. [22] outlined the impacts of the COVID-19 pandemic on responsible production and consumption, opening possible opportunities for India to "build back better" during the post-pandemic recovery. Sebestyén and Abonyi [23] developed a comprehensive SDG performance measurement tool that could be applied to monitor India's performance in achieving SDG 12 and identify areas for improvement.

2.2. Strategies and priorities for achieving SDG 12

Meeting the goal of SDG 12 would require a holistic approach to India's production and consumption aspects. Bengtsson et al. [5] argued that this may not be just an issue of efficiency but an overall consumption volume with concomitant social and institutional change. In the Indian scenario, this would call for policies that not only improve efficiency in production methods but also affect patterns of consumption. Leal Filho et al. [6] brought to our attention the function of design thinking in achieving sustainable development goals and how this may be applicable for innovative SCP strategies tailored to the challenges facing India. Geels et al. [9] had a "reconfiguration" position focusing on the transition in socio-technical systems and the daily practices embedded with it; such a concept can allow India to understand systemic shifts in consumption and production practices. Roy and Singh [24] identified five principal themes of the business focus in the literature of SPC, thereby providing a structured approach to address the implementation issues that India may face at both strategic and operational levels. Thus, by giving importance to such sustainable production practices, India may achieve the goals of SDG 12. Mangla et al. [8] followed the fuzzy analytical hierarchy process to evaluate barriers toward SCP trends, and similarly, it can be applied to finding those areas of focus for the Indian case. Trummer et al. [25] came forward with measures regarding mineral raw materials' consumption by bringing it down further to fulfill sustainability strategies, which the Indian manufacturing sector must follow. Further, Sharma et al. [26] indicated an opportunity for Industry 4.0 technologies to reach SDG 12 by requiring a need to invest in digital transformation for its industries within India. The challenges of SPCs analyzed through a PEST-AHP methodology were suggested with a proposed framework by Goyal et al. [27] for rank evaluation across Indian sectors of barriers. Kunskaja et al. [28] analyzed the implementation of innovative energy technologies and their alignment with SDG 12, giving insight into India's contributions to the energy sector for sustainable production practices.

The other dimension of achieving SDG 12 in India should be promoting sustainable consumption. According to Vallet-Bellmunt et al. (2023), who measured the contribution of the food retailers' sector to SDG 12, it called for increased involvement in disclosing their sustainability performance. Similar actions can be adopted to make Indian consumers aware of the importance of promoting responsible consumption. Jastrzębska [29] put forth the best practices to achieve SDG 12 in cities, which may be tailored to India's cities and towns to help realize sustainable consumption. Vergragt et al. [30] called for more research on sustainable production, consumption, and livelihoods at the global and regional levels and recommended that India invest in such research to inform context-specific SCP strategies [31]. proposed the use of consumer footprint as an indicator to monitor SDG 12, which can be adopted to assess and direct India's progress on sustainable consumption.

Some sector-specific challenges need to be addressed for India to achieve SDG 12. Liu et al. [10] identified barriers related to sustainable food consumption and production from a circular economy perspective that are relevant to India's agricultural and food processing sectors. Olabi et al. [32] discussed the potential of green ammonia to achieve SDG 12, which has some implications for India's chemical and fertilizer industries. These sector-specific approaches will help India focus on SCP practices in key sectors. Raman et al. [33] have identified key research contributions and policy insights for SDG 12, which calls for a multi-faceted approach to e-waste management and sustainable practices in India. Castellano et al. [34] conducted an efficiency analysis to achieve SDG 12 by providing India with guidelines about the performance of different sectors of activities with potential areas for improvement.

In addition, more robust monitoring and assessment frameworks will be needed to track India's progress on SDG 12. According to Confraria et al. [35], an analysis of countries' research priorities about the SDGs shows that their priorities need to be aligned with the national challenges of the SDGs. For India, that means investing in related SDG 12 research. Dinçer et al. [36] provide an integrated decision-making

Table 1
Identified practices.

Practice	Description	Explanation for Non-Domain Readers (Simplified & Accessible)	Refs.
Implement circular economy practices (P1)	Focuses on reducing waste, reusing resources, and recycling materials in production processes to minimize environmental impact and maximize resource efficiency.	A circular economy works like a loop where products and materials are continually reused instead of thrown away. This reduces pollution, saves resources, and cuts costs for industries. Think of it as shifting from a *"use–throw–replace"* model to a *"use–reuse–repair–recycle"* system.	Shaikh et al. [3]; Leal Filho et al. [40]; Liu et al. [10]
Adopt green marketing and eco-labeling (P2)	Promotes environmentally friendly products through transparent communication and labeling, enabling consumers to make informed, sustainable choices.	Green marketing helps consumers identify products that are better for the environment. Eco-labels act as a quick guide—similar to nutrition labels—helping buyers choose products that use fewer chemicals, less energy, or are responsibly sourced.	Abbas et al. [12]; Marcos et al. [37]
Enhance regulatory frameworks and policies (P3)	Develop and enforce stricter environmental regulations and policies to guide businesses towards sustainable practices and responsible resource use.	These are government rules that require companies to reduce pollution, use cleaner technologies, or follow sustainability standards. Clear and strong policies push industries to act responsibly and prevent environmental damage.	Stevens [41]; Trummer et al. [25]; Liu et al. [10]
Invest in sustainable technologies (P4)	Implement innovative technologies like Industry 4.0 and digital solutions to improve resource efficiency, reduce waste, and optimize production processes.	Sustainable technologies include automation, IoT sensors, AI, and energy-efficient machinery. These tools help companies monitor resource use, reduce wastage, and make smarter decisions—similar to how smart meters reduce home electricity bills.	Sharma et al. [26]; Kunskaja et al. [28]; Sharma et al. [2]
Promote sustainable supply chain management (P5)	Integrate sustainability criteria throughout the supply chain, from sourcing to distribution, to ensure responsible production practices.	This means ensuring that raw materials are responsibly sourced, transportation is energy-efficient, and suppliers follow environmental standards. A sustainable supply chain improves transparency and reduces the overall footprint of products—from factory to consumer.	Mangla et al. [8]; Luthra et al. [7]; Liu et al. [10]
Encourage sustainable consumption education (P6)	Raise awareness and educate consumers about sustainable consumption patterns, empowering them to make environmentally conscious decisions.	This involves awareness campaigns, school programs, and digital tools that help people understand how their daily choices—energy use, food waste, product selection—impact the environment. It empowers consumers to make greener decisions.	Cuesta et al. [1]; Marcos et al. [37]; Liu et al. [10]
Develop sustainable product design (P7)	Create products with longer lifespans, easier repair and recycling capabilities, and reduced environmental impact throughout their lifecycle.	Sustainable design means making products that last longer, can be repaired easily, and use materials that can be recycled. For example, modular electronics or biodegradable packaging reduce long-term waste.	Leal Filho et al. [40]; Marcos et al. [37]
Implement sustainable food systems (P8)	Reduce food waste, promote sustainable agriculture, and optimize food distribution to ensure responsible consumption and production in the food sector.	Sustainable food systems make farming more efficient and less harmful while ensuring food reaches people without waste. Examples include precision farming, composting, and cold-chain systems that prevent spoilage.	Summerhayes et al. [16]; Mensah et al. [11]; Sharma et al. [2]
Foster multi-stakeholder partnerships (P9)	Collaborate across sectors and industries to share knowledge, resources, and best practices for sustainable production and consumption.	Sustainability challenges cannot be solved by one group alone. Partnerships between businesses, governments, researchers, and communities help combine expertise, reduce duplication, and scale solutions faster.	de Visser-Amundson [42].; Opoku et al. [43]; Mangla et al. [8]
Adopt life cycle assessment approaches (P10)	Use comprehensive environmental impact assessments to guide product development and production process decision-making.	LCA looks at everything—from extracting raw materials to manufacturing, using the product, and disposing of it. It helps identify where the biggest environmental impacts occur, guiding smarter design and policy decisions.	Sala & Castellani [31]; Cordella et al. [44]
Promote sustainable urban planning (P11)	Design cities and infrastructure to support sustainable consumption patterns and efficient resource use.	Sustainable urban planning includes green buildings, efficient public transport, waste-management systems, and energy-saving infrastructure—creating healthier, low-carbon cities.	Summerhayes et al. [16]; Han et al. [18]
Implement sustainable procurement practices (P12)	Integrate sustainability criteria into purchasing decisions for both public and private sectors to drive market demand for sustainable products.	When governments and businesses choose suppliers based on environmental and social standards, it pushes the entire market toward greener products. This creates demand for sustainable goods and services.	Opoku et al. [43]; Luthra et al. [7]

approach for SDG disclosures that applies to evaluating SCP practices in India that require priority. These could help India identify areas it needs to focus on most and monitor progress toward realizing SDG 12. Marcos et al. [37] reported opportunities and overlooked issues in the implementation of SDG 12, thus allowing India to develop a more holistic way of approaching SCP. Pandey and Asif [38] measured the energy and environmental sustainability in South Asia vis-à-vis the context of SDGs and brought regional background to India's efforts towards SDG 12. Rweyendela [39] introduced the approach toward industrial ecology principles through environmental impact assessment, one approach India might have while integrating SCP in its regulation Table 1.

Many research studies have been conducted to identify numerous sustainable consumption and production practices. However, relatively few studies focus on the Indian context using the MCDM technique. Very few studies study the barriers concerning sustainable consumption and production, as identified by Goyal et al. [4] and Luthra et al. [7]. Very few research focuses on positive practices, especially for prioritization in India. This gap prevents Indian policymakers and decision-makers from efficiently allocating resources and energy toward the most impactful practices in achieving SDG 12 in the most suitable socio-economic and environmental contexts. A systematic approach for prioritizing appropriate sustainable consumption and production would provide valuable insights for implementational strategies and policy formation in India.

3. Methodology

This study employs a systematic methodology to identify and prioritize sustainable consumption and production (SCP) practices to achieve SDG 12 in India. The methodology integrates the Grey Delphi and Grey DEMATEL approaches to address the challenges associated with human judgment, incomplete information, and the interrelationships among practices Table 2.

3.1. Grey Delphi approach

The Grey Delphi method combines the principles of the traditional Delphi technique with the grey set theory to refine and achieve consensus on SCP practices. The method was proposed by Dalkey and Helmer in 1963. The steps involved are as follows:

Step 1: Identification of SCP practices

An extensive literature review was conducted to identify 12 key SCP practices relevant to SDG 12 in India. Sources included journal articles, policy documents, and industry reports. The identified practices formed the basis of a questionnaire distributed to experts.

Step 2: Expert panel selection

A panel of 10 experts was selected, including policymakers, sustainability professionals, academicians, and industry practitioners with diverse expertise in sustainable development and SCP practices Table 3.

Step 3: Data collection using a linguistic scale

Experts assessed the importance of each SCP practice using a linguistic scale (see Table 4), which was subsequently converted into grey numbers.

Step 4: Creating the grey numbers

The collected responses changed into the corresponding grey numbers based on Table 4. These grey numbers are then used as the basis for successive analyses. Assume that the expert panel is comprised of k members for evaluation, then the assessment of the barrier $\otimes H_i$ is determined as follows (Bhattacharyya, 2015):

Table 3
Expert panel composition.

Expert No.	Role	Field of Expertise	Experience (Years)	Highest Qualification
1	Policymaker	Regulatory Frameworks and Policies	15	Master's in Public Administration
2	Sustainability Professional	Circular Economy Practices	12	MBA in Sustainability
3	Academic Researcher	Sustainable Product Design	10	Ph.D. in Sustainable Design
4	Industry Practitioner	Sustainable Technologies	8	Bachelor's in Engineering
5	Policymaker	Urban Planning	20	Master's in Urban Development
6	Sustainability Professional	Supply Chain Management	15	MBA in Supply Chain
7	Academic Researcher	Sustainable Consumption Education	18	Ph.D. in Environmental Education
8	Industry Practitioner	Green Marketing and Eco-labeling	14	Master's in Business
9	Policymaker	Multi-Stakeholder Partnerships	12	Ph.D. in Political Science
10	Sustainability Professional	Life Cycle Assessment	10	Master's in Environmental Science

Table 2
Justification for using proposed method.

Method	Ability to Handle Uncertainty	Captures Interdependence Between Criteria	Identifies Cause-Effect Relationships	Expert Judgment Requirements	Suitability for SCP Context
AHP	Low - uses crisp pairwise judgments; sensitive to inconsistency	Limited - assumes hierarchical, one-way relationships	No	High cognitive load due to many comparisons; requires consistency	Moderate - works for simple, stable systems but not ideal for dynamic SCP interactions
TOPSIS	Low - distance- based calculation assumes precise data.	None - does not capture interactions	No	Moderate; requires rating alternatives on criteria	Low- Moderate - useful for final ranking but cannot reveal influence structure among SCP practices
ANP	Low - relies on crisp judgments	High - allows feedback and interdependence	No	Very high; complex pairwise comparisons across networks	Moderate - captures complexity but too demanding for data-scarce SCP contexts
Fuzzy DEMATEL	Moderate- High - handles imprecision via fuzzy numbers	High -DEMATEL models interrelationships	Yes- identifies cause/ effect through D-R	Requires defining membership functions. adding subjectivity	High - suitable for uncertainty-heavy systems but depends heavily on quality of membership functions
Grey Delphi-Grey DEMATEL (proposed)	Very High -grey intervals naturally represent incomplete or inconsistent expert data without membership functions	High - DEMATEL structure models mutual influence	Yes-identifies structural drivers using D-R and prominence values	Low-Moderate - linguistic inputs converted to grey intervals reduce cognitive burden	Very High - ideal for SCP where data gaps, expert disagreement, and policy uncertainty are common

Table 4
Linguistic scale.

Linguistics Term	Grey Number
No influence (NI)	[0, 0]
Very low influence (VLI)	[0, 1]
Low influence (LI)	[1, 2]
High influence (HI)	[2, 3]
Very high influence (VHI)	[3, 4]

$$\otimes H_i = \frac{\left(\otimes H_i^1 + \otimes H_i^2 + \ldots + \otimes H_i^h + \ldots + \otimes H_i^k\right)}{k} \quad (1)$$

where $\otimes H_i$ is the total evaluation of barrier importance and $\otimes H_i^h$ denotes that h^{th} expert's evaluation of barrier i from the adopted problem.

Step 5: Whitening of the grey numbers

Considers the $\tilde{\otimes}$ as a whitenisation value of the general interval grey number $\otimes H_i = [\underline{H}, \overline{H}] = [H' \epsilon H \, | \underline{H} \leq H' \leq \overline{H}]$. When the $\tilde{\otimes}$ has unknown distribution, the whitenisation could be done through Eq. (2) (Liu and Forrest, 2010; Liu et al., 2012):

$$\tilde{\otimes} = \beta.\underline{H} + (1-\beta).\overline{H}, \; \beta = [0,1] \quad (2)$$

If the β coefficient is 0.5, $\tilde{\otimes}$ is known as equal weight mean whitenisation, which is a commonly used value fora (Liu and Forrest, 2010).

Step 6: Setting a threshold and refining practices

A predefined threshold value (e.g., $\lambda = 3.5$) was used to filter and finalize the significant SCP practices. If $\tilde{\otimes}$ is equal to or greater than λ, the practice is chosen; otherwise, it is rejected.

3.2. Grey DEMATEL approach

The Grey DEMATEL method was employed to explore the interrelationships among the selected SCP practices and to classify them into cause-and-effect groups. The steps include:

Step 1: Constructing the initial direct-relation matrix

To determine the influence of one practice on another, a pairwise comparison matrix ($d = \{d_i | i = 1, 2, \cdots, n\}$) was established using expert inputs and a linguistic scale on five-point grey points (Table 1).

Step 2: Develop the grey direct-relation matrix

Linguistic evaluations were translated into grey numbers to construct the initial grey direct-relation matrix, with each expert's input contributing to the aggregated matrix. With responses from K experts, the resulting K grey direct relationship matrices, denoted as $Y^1, Y^2, Y^3, \ldots, Y^k$, are derived. The expression for the representation of the grey matrix depicting direct relations is given by Eq. (3) as follows:

$$Y^k = \begin{bmatrix} 0 & \otimes y_{12k} & \otimes y_{13k} & \cdots & \otimes y_{1(n-1)k} & \otimes y_{1nk} \\ \otimes y_{21k} & 0 & \otimes y_{23k} & \cdots & \otimes y_{2(n-1)k} & \otimes y_{2nk} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \otimes y_{(n-1)1k} & \otimes y_{(n-1)2k} & \otimes y_{(n-1)3k} & \cdots & 0 & \otimes y_{(n-1)nk} \\ \otimes y_{n1k} & \otimes y_{n2k} & \otimes y_{n3k} & \cdots & \otimes y_{n(n-1)k} & 0 \end{bmatrix} \quad (3)$$

The element of $[Y]$, $\otimes y_{ijk} = \left(\underline{\otimes} y_{ijk}, \overline{\otimes} y_{ijk}\right)$ shows the influence of practice 'i' on practice 'j' by the kth expert. The $\underline{\otimes} y_{ijk}$ represents the lower and $\overline{\otimes} y_{ijk}$ the upper limit of grey values.

Step 3: Develop the total grey relation matrix

The total grey relation matrix is obtained by combining all individual grey direct-relation matrices using Eq. (4).

$$\otimes Y = \sum_{i=0}^{K} \left(\frac{\sum \underline{\otimes} y_{ijk}}{K}, \frac{\sum \overline{\otimes} y_{ijk}}{K} \right) \quad (4)$$

Step 4: Express the normalised grey direct-relation matrix

The grey relation matrix is normalized into the grey direct-relation matrix N using Eqs. (5)–(7).

$$\otimes s = \left[\underline{s}, \; \overline{s}\right] = \frac{1}{\max_{0 \leq i \leq n} \sum_{j=0}^{n} \otimes Y_{ij}} \; i.\, j = 1, 2, 3, \ldots, n \quad (5)$$

$$N = \otimes s.\, X \quad (6)$$

$$\otimes n_{ij} = \left[\underline{s}.\, \otimes y_{ijk}, \; \overline{s}.\, \otimes y_{ijk}\right] \quad (7)$$

Step 5: Compute the total relation matrix

The total relation matrix T is derived from the normalized grey direct-relation matrix using Eq. (8).

$$\otimes T = \otimes N.(\otimes I - \otimes N)^{-1} \quad (8)$$

where "$\otimes I$" is the grey identity matrix.

Step 6: Calculate the causal parameters

To determine the causal parameter Eqs. (9) and (10) are used.

$$\otimes r_i = \sum_{j=1}^{n} t_{ij} \; \forall_i \quad (9)$$

$$\otimes c_j = \sum_{i=1}^{n} t_{ij} \; \forall_j \quad (10)$$

The practice "i" influence is shown by $\otimes r_i$, which implies the total influence of practices, and the $\otimes c_j$ signifies the influence received by practice "j" from the other practices.

Step 7: Computation of the prominence and net effect

The prominence ($\otimes P_i$) and net effect ($\otimes E_i$) score of the practices are determined using expressions (11) and (12):

$$\otimes P_i = \otimes r_i + \otimes c_j | i = j \quad (11)$$

$$\otimes E_i = \otimes r_i - \otimes c_j | i = j \quad (12)$$

Based on the prominence ($\otimes P_i$) and net effect ($\otimes E_i$) scores, the causal relationship graph is constructed. A positive value of $\otimes E_i$ indicates the net effect (cause) of practice on the system, while a negative value represents the net influence of the system on the practice.

Step 8: Constructing the causal diagram

A causal diagram was developed to visually represent the interdependencies among SCP practices, highlighting their roles in achieving SDG 12.

4. Analysis

4.1. Grey Delphi analysis

The literature review identified 12 SCP practices for achieving SDG 12 in India. The expert panel evaluated these practices. Table 5 summarizes the grey and crisp values derived through the Grey Delphi process.

Practices with crisp values exceeding the threshold of 3.5 were considered significant. All 12 practices were accepted for further analysis. Fig. 1 displays the crisp values for the 12 practices. Practices above the red threshold line (3.5) are significant for achieving SDG 12.

The Grey Delphi analysis in Table 5 successfully validated and prioritized all twelve initially identified SCP practices pertinent to achieving SDG 12 in India. Through expert evaluation using a linguistic scale converted into grey numbers and subsequent crisp value calculation, every practice achieved a crisp score above the threshold value of 3.5, indicating strong consensus on their significance. Practices such as implementing circular economy practices (P1), investing in sustainable technologies (P4), and promoting sustainable urban planning (P11) emerged with particularly high crisp values of 4.5 and 4.6, reflecting the expert panel's strong agreement on their critical role in advancing sustainability goals. The consistency of the high scores across all practices

Table 5
Grey and crisp values for SCP practices.

Practice	Grey Value Range	Crisp Value	Decision
Implement circular economy practices (P1)	[4.2, 4.8]	4.5	Accepted
Adopt green marketing and eco-labeling (P2)	[4.0, 4.6]	4.3	Accepted
Enhance regulatory frameworks and policies (P3)	[3.8, 4.6]	4.2	Accepted
Invest in sustainable technologies (P4)	[4.3, 4.9]	4.6	Accepted
Promote sustainable supply chain management (P5)	[4.1, 4.7]	4.4	Accepted
Encourage sustainable consumption education (P6)	[3.7, 4.3]	4.0	Accepted
Develop sustainable product design (P7)	[3.9, 4.5]	4.1	Accepted
Implement sustainable food systems (P8)	[4.0, 4.6]	4.3	Accepted
Foster multi-stakeholder partnerships (P9)	[4.2, 4.8]	4.5	Accepted
Adopt life cycle assessment approaches (P10)	[3.8, 4.6]	4.2	Accepted
Promote sustainable urban planning (P11)	[4.3, 4.9]	4.6	Accepted
Implement sustainable procurement practices (P12)	[4.1, 4.7]	4.4	Accepted

suggests a broad recognition that an integrated and multi-dimensional approach is required to effectively address India's SCP challenges. Notably, the selection outcome ensures that key domains such as regulatory frameworks, supply chain management, sustainable product design, and life cycle assessment — are given due attention, aligning technical, policy, and behavioral interventions. By leveraging the Grey Delphi method, the study minimized biases and enhanced reliability in expert judgment, thereby strengthening the foundation for subsequent causal analysis using Grey DEMATEL. The outcomes of Table 4 thus provide a validated, context-specific framework for guiding policymakers, businesses, and stakeholders in prioritizing and implementing the most impactful SCP practices in India's unique socio-economic and environmental landscape.

4.2. Grey DEMATEL analysis

Using the refined list of 12 SCP practices, the Grey DEMATEL approach analyzed interrelationships and categorized practices into cause-and-effect groups. Table 6 presents the total grey relation between the practices, which is normalized using Eqs. (5)–(7) (see Table 7). Then, using Eq. (8), the total relation matrix has been computed (see Table 8). Table 9 shows the practices' prominence (β) and net effect (γ) scores and Fig. 1 depicts the causal diagram.

Based on the results presented in Table 9 obtained through the Grey DEMATEL analysis, the study successfully classified the 12 SCP practices into cause-and-effect groups while highlighting their relative importance and interrelations. Practices such as "Implement circular economy practices" (P1), "Adopt green marketing and eco-labeling" (P2), "Enhance regulatory frameworks and policies" (P3), "Invest in sustainable technologies" (P4), "Develop sustainable product design" (P7), "Implement sustainable food systems" (P8), "Foster multi-stakeholder partnerships" (P9), and "Adopt life cycle assessment approaches" (P10) were identified as cause group practices, given their positive net effect (γ) values. Among these, P1, P9, and P10 recorded the highest net effect scores, implying that they are primary drivers influencing other SCP practices within the system. In contrast, practices like "Promote sustainable supply chain management" (P5), "Encourage sustainable consumption education" (P6), "Promote sustainable urban planning" (P11), and "Implement sustainable procurement practices" (P12) were categorized as effect group practices, indicating that they are more likely to be influenced by the cause group actions. The prominence (β) values revealed that "Implement circular economy practices" (P1) and "Foster multi-stakeholder partnerships" (P9) held the most significant total influence within the network, underlining their pivotal roles in promoting SCP outcomes. The Grey DEMATEL analysis provided a clear hierarchical structure of the practices, offering critical insights for policymakers to focus on reinforcing high-causal-effect practices to drive systemic improvements toward achieving SDG 12 in India. This nuanced understanding of cause-and-effect relationships among SCP practices ensures more strategic prioritization and resource allocation in policy and implementation efforts. Fig. 2 illustrates SCP practices as nodes linked by directed edges of varying strength, representing their influence. "Cause" practices are placed on the left-hand side, influencing changes in the right-hand side "effect" practices.

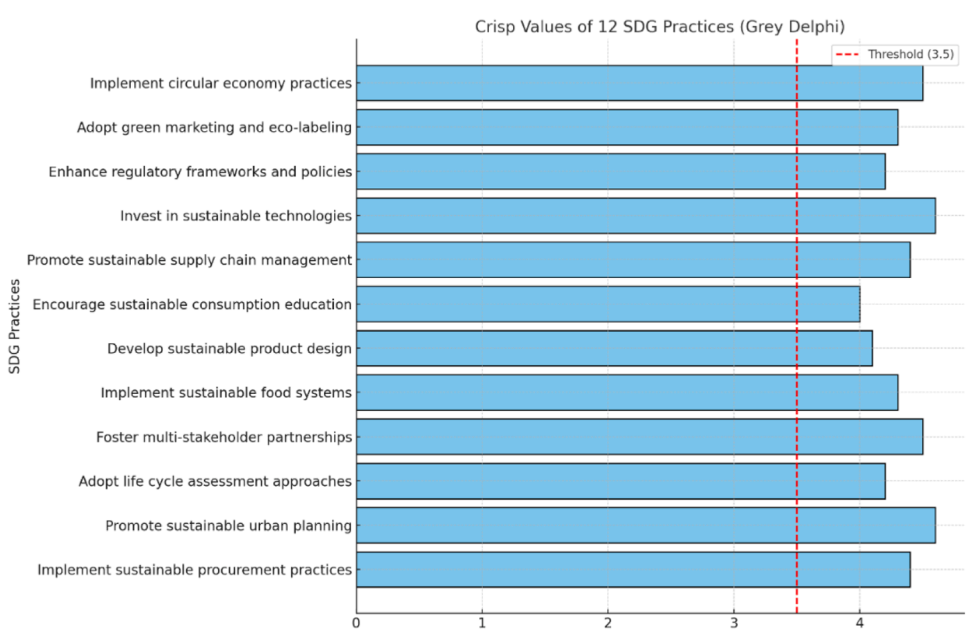

Fig. 1. Finalization of SDG practices based on threshold value.

Table 6
Total grey relation matrix.

SCP	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
P1	0.00	3.75	3.73	3.75	4.90	4.88	3.73	3.70	3.75	3.75	4.93	3.73
P2	3.60	0.00	3.58	3.60	4.75	4.73	3.58	3.55	3.60	3.60	4.78	3.58
P3	3.48	3.48	0.00	3.48	4.63	4.60	3.45	3.43	3.48	3.48	4.65	3.45
P4	3.40	3.40	3.38	0.00	4.55	4.53	3.38	3.35	3.40	3.40	4.58	3.38
P5	1.80	1.80	1.78	1.80	0.00	2.93	1.78	1.75	1.80	1.80	2.98	1.78
P6	1.88	1.88	1.85	1.88	3.03	0.00	1.85	1.83	1.88	1.88	3.05	1.85
P7	3.53	3.53	3.50	3.53	4.68	4.65	0.00	3.48	3.53	3.53	4.70	3.50
P8	3.40	3.40	3.38	3.40	4.55	4.53	3.38	0.00	3.40	3.40	4.58	3.38
P9	3.70	3.70	3.68	3.70	4.85	4.83	3.68	3.65	0.00	3.70	4.88	3.68
P10	3.65	3.65	3.63	3.65	4.80	4.78	3.63	3.60	3.65	0.00	4.83	3.63
P11	1.73	1.73	1.70	1.73	2.88	2.85	1.70	1.68	1.73	1.73	0.00	1.70
P12	3.28	3.28	3.25	3.28	4.43	4.40	3.25	3.23	3.28	3.28	4.45	0.00

Table 7
Normalized grey relation matrix.

SCP	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
P1	0.00	0.76	0.76	0.76	0.99	0.99	0.76	0.75	0.76	0.76	1.00	0.76
P2	0.73	0.00	0.73	0.73	0.96	0.96	0.73	0.72	0.73	0.73	0.97	0.73
P3	0.71	0.71	0.00	0.71	0.94	0.93	0.70	0.70	0.71	0.71	0.94	0.70
P4	0.69	0.69	0.69	0.00	0.92	0.92	0.69	0.68	0.69	0.69	0.93	0.69
P5	0.37	0.37	0.36	0.37	0.00	0.59	0.36	0.36	0.37	0.37	0.60	0.36
P6	0.38	0.38	0.38	0.38	0.61	0.00	0.38	0.37	0.38	0.38	0.62	0.38
P7	0.72	0.72	0.71	0.72	0.95	0.94	0.00	0.71	0.72	0.72	0.95	0.71
P8	0.69	0.69	0.69	0.69	0.92	0.92	0.69	0.00	0.69	0.69	0.93	0.69
P9	0.75	0.75	0.75	0.75	0.98	0.98	0.75	0.74	0.00	0.75	0.99	0.75
P10	0.74	0.74	0.74	0.74	0.97	0.97	0.74	0.73	0.74	0.00	0.98	0.74
P11	0.35	0.35	0.35	0.35	0.58	0.58	0.35	0.34	0.35	0.35	0.00	0.35
P12	0.66	0.66	0.66	0.66	0.90	0.89	0.66	0.65	0.66	0.66	0.90	0.00

Table 8
Total relation matrix.

SCP	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
P1	-0.49	-0.06	-0.06	-0.06	-0.12	-0.12	-0.06	-0.06	-0.06	-0.06	-0.12	-0.06
P2	-0.06	-0.48	-0.06	-0.06	-0.12	-0.11	-0.06	-0.06	-0.06	-0.06	-0.12	-0.06
P3	-0.06	-0.06	-0.47	-0.06	-0.11	-0.11	-0.06	-0.06	-0.06	-0.06	-0.11	-0.06
P4	-0.06	-0.06	-0.06	-0.47	-0.11	-0.11	-0.06	-0.06	-0.06	-0.06	-0.11	-0.06
P5	-0.04	-0.04	-0.04	-0.04	-0.40	-0.02	-0.04	-0.04	-0.04	-0.04	-0.02	-0.04
P6	-0.04	-0.04	-0.04	-0.04	-0.03	-0.40	-0.04	-0.05	-0.04	-0.04	-0.02	-0.05
P7	-0.06	-0.06	-0.06	-0.06	-0.11	-0.11	-0.48	-0.06	-0.06	-0.06	-0.12	-0.06
P8	-0.06	-0.06	-0.06	-0.06	-0.11	-0.11	-0.06	-0.47	-0.06	-0.06	-0.11	-0.06
P9	-0.06	-0.06	-0.06	-0.06	-0.12	-0.12	-0.06	-0.06	-0.49	-0.06	-0.12	-0.06
P10	-0.06	-0.06	-0.06	-0.06	-0.12	-0.12	-0.06	-0.06	-0.06	-0.49	-0.12	-0.06
P11	-0.04	-0.04	-0.04	-0.04	-0.02	-0.02	-0.04	-0.04	-0.04	-0.04	-0.39	-0.04
P12	-0.06	-0.06	-0.06	-0.06	-0.10	-0.10	-0.06	-0.06	-0.06	-0.06	-0.10	-0.46

5. Discussion

The Grey DEMATEL analysis of SCP practices for realizing SDG 12 in India brought rich insights into the causal relationship among the twelve SCP practices. Categorizing practices into cause-and-effect groups gives strategic support to ordering implementation priorities. Findings show that "Implement circular economy practices" (P1) with the highest prominence (β=7.5) and net effect (γ=3.6) scores are the most impactful practice, indicating its consequential status as a catalyst for sustainable development. This is consistent with Shaikh et al. [3], who noted that responsible consumption and production were possible through systemic means subject to resource constraints. The prominence of the circular economy's focus on minimizing waste, reusing resources, and recycling materials directly addresses the issues of resource depletion in India's booming economy. Likewise, "Foster multi-stakeholder partnerships" (P9), with a prominence score of 7.4 and net effect score of 3.5, was another key driver, reinforcing de Visser-Amundson's [42] position that inter-sector collaboration is imperative for resolving complex issues of sustainability. The strong causal power of the "Adopt life cycle assessment approaches" (P10), with a prominence score of 7.3, reaffirms Sala and Castellani's [31] finding that holistic environmental impacts are a prerequisite for tracking progress towards SDG 12. These three practices constitute the core of a systemic approach to SCP in India, as they have multiple domain impacts with synergetic effects and cascades of positive impacts throughout the system. The causal map showcases how these practices directly affect effect group practices with a cascade of positive effects within the entire SCP system. This hierarchical perspective allows policymakers to plan for transmitting systemic gains from these key practices while avoiding singular attention to individual practices.

The effect practices, such as "Promote sustainable supply chain management" (P5), "Encourage sustainable consumption education" (P6), "Promote sustainable urban planning" (P11), and "Implement sustainable procurement practices" (P12), are key areas with high susceptibility towards influence from cause group practices. While categorized as effect practices, they have high prominence scores, suggesting they are the most important parts of the overall SCP framework. Sustainable supply chain management (P5), with a prominence value of 5.9,

Table 9
Prominence (β) and net effect (γ) scores of SCP practices.

Practice	Prominence (β)	Net Effect (γ)	Role
Implement circular economy practices (P1)	7.5	3.6	Cause
Adopt green marketing and eco-labeling (P2)	7.2	3.3	Cause
Enhance regulatory frameworks and policies (P3)	6.9	3.1	Cause
Invest in sustainable technologies (P4)	6.8	2.9	Cause
Promote sustainable supply chain management (P5)	5.9	-2.6	Effect
Encourage sustainable consumption education (P6)	6.0	-2.4	Effect
Develop sustainable product design (P7)	7.0	3.2	Cause
Implement sustainable food systems (P8)	6.7	3.0	Cause
Foster multi-stakeholder partnerships (P9)	7.4	3.5	Cause
Adopt life cycle assessment approaches (P10)	7.3	3.4	Cause
Promote sustainable urban planning (P11)	5.8	-2.8	Effect
Implement sustainable procurement practices (P12)	6.2	-2.5	Effect

endorses Mangla et al.'s [8] finding that supply chains are key areas of intervention for sustainable consumption and production. Its negative net effect value of -2.6 implies that the practice derives a massive benefit from improvements in the application of circular economy thinking and regulatory frameworks. Similarly, sustainable consumption education (P6) with a prominence value of 6.0 aligns with Cuesta et al.'s [1] focus on awareness of alternative consumption patterns. Interrelation analysis infers that educational initiatives are more effective with accompanying green marketing and multi-stakeholder partnerships. Sustainable urban planning (P11), although with the lowest prominence value of 5.8, is key to creating environments conducive to sustainable consumption, as Summerhayes et al. [16] noted. It is evident from the analysis that initiatives in urban areas need to be linked with circular economy thinking and life cycle analyses to achieve maximum effects. Sustainable procurement practices (P12) with a prominence value of 6.2 align with Opoku et al.'s [43] work regarding procurement in construction to achieve SDG 12. It is apparent from the causal diagram that having strong cause group practices helps to build a conducive ecosystem for successfully pursuing these effect group practices. This helps identify a more effective resource utilization by understanding that enhancing effect practices depends on strong cause practices.

Prioritization of SCP practices using Grey DEMATEL provides insightful recommendations for sector-specific action plans for Indian implementation. For the country's manufacturing sector, a major contributor to Indian economic growth, the high priority for establishing circular economy practices (P1) and employing sustainable technologies (P4) implies that these should be high-priority areas. This resonates with Sharma et al.'s [26] discovery that Industry 4.0 technologies provide strategic avenues for achieving SDG 12, especially with the support of institutional pressure. For the agricultural sector, a backbone of India's economy and society, as well as the food sector, the most benefits can be derived from establishing sustainable food systems (P8) and applying life cycle assessment methods (P10). This resonates with Mensah et al.'s [11] discovery of conceptual issues with tracking changes in sustainable consumption of foods and Liu et al.'s [10] research indicating barriers to sustainable food systems from a circular economy viewpoint. For India's burgeoning construction sector, with its rapid growth, the sector can benefit from a focus on sustainable product design (P7) together with regulatory frameworks (P3), as per Cosentino et al.'s [21] research using bio-based construction materials as drivers of the SDGs. For India's growing service sector, incorporating green marketing and eco-labeling (P2) presents a major practice for advancement, complementing Abbas et al.'s [12] research using eco-labeling and green advertising to achieve SDG 12. The role of the public sector is underscored through the significance of improving regulatory frameworks and regulations (P3), as indicated by Trummer et al.'s [25] discovery of measurement sets for achieving SDG target 12.2. These sector-based implications offer a focused method of implementing SCP practices for India's widespread economic base while recognizing that varying sectors may need different focal points while the comprehensive goal of achieving overall SDG 12 is pursued.

Prioritization of SCP practices within India poses significant challenges that necessitate focused policy interventions. The resourcefulness scores of circular economy practices (P1) and multi-stakeholder partnerships (P9) are juxtaposed with the literature-established existing barriers. Goyal et al. [4] highlighted organizational, government, and financial barriers as significant challenges to SCP adoption of Indian manufacturing, while Luthra et al. [7] underscored the importance of government support and policies. This implies that improvements to

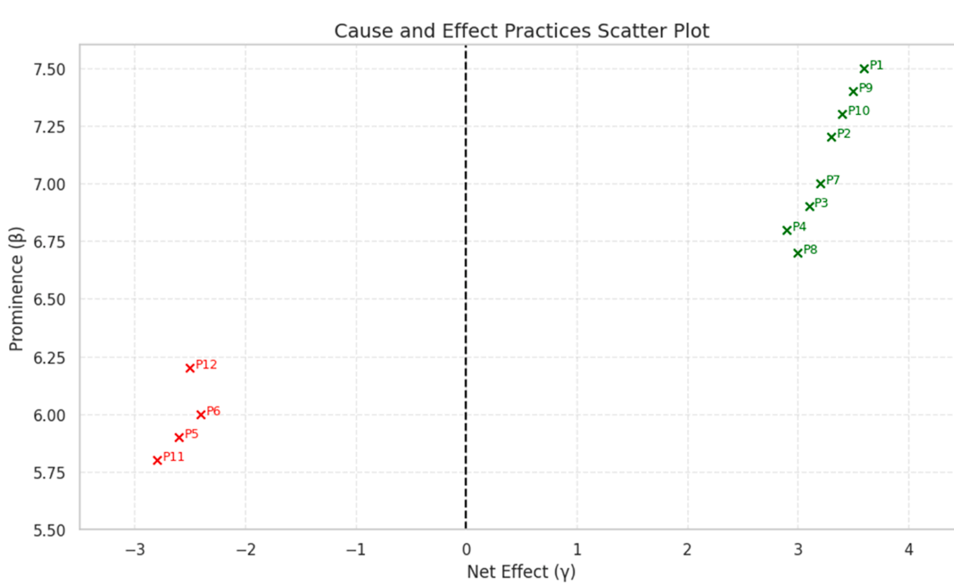

Fig. 2. Causal relationship diagram.

policy frameworks must take precedence to embed high-impact cause group practices. Policies must address technological and financial constraints noted by Mangla et al. [8] to enable the effective adoption of a circular economy. The strength of regulatory frameworks (P3) is that they are significant direct influencers of sustainable supply chain management (P5) and procurement practices (P12), which implies a ripple effect within the system. Awareness, as well as behavioral barriers noted by Liu et al. [10], can be overcome by strategic support for sustainable consumption education (P6) through synchronization with green marketing campaigns (P2). The causal diagram graphically captures interactions of practices, establishing a template for sequencing of policies. The relative position of sustainable urban planning (P11) as a resultant practice with the least prominence implies that it is dependent for effectiveness primarily on strong support from other practices, much as noted by Han et al.'s [18] research seeking municipal-level sustainable development policies. This interconnection necessitates a holistic policy approach rather than individual interventions. Findings validate Bengtsson et al.'s [5] proposition that change in consumption and production patterns requires transcendence of efficiency to confront absolute levels of resource utilization, institutions, and social practices. For India, that implies creating comprehensive packages of policies that set about addressing multiple practices simultaneously while factoring their causal interactions, offering financial rewards for business models with a circular orientation, introducing regulatory frameworks designed to foster innovative technological development for sustainability, as well as educational initiatives promoting changes towards patterns of consumption that are sustainable.

6. Managerial and theoretical implications

This research provides substantial practical implications for Indian policymakers, business leaders, and sustainability practitioners. First, the cause-effect grouping of SCP practices gives decision-makers a distinct strategic path to resource allocation. By focusing on high-prominence cause practices such as the adoption of circular economy approaches (P1), developing multi-stakeholder partnerships (P9), and embracing life cycle approaches (P10), managers can capitalize on cascading effects of their investment in other practices, with a maximum return on investment. For business leaders, the research results recommend giving precedence to incorporating circular economy approaches within business models over stand-alone initiatives for sustainability, as these changes have systemic benefits. The high prominence of eco-labeling and green marketing (P2) implies that open communication of efforts towards sustainability is a strategic market differentiator for operators of businesses in the rapidly environmentalized Indian market. For supply chain managers, positioning sustainable supply chain management (P5) as a resulting practice implies its success depends on the prior development of regulatory frameworks and the adoption of circular economy approaches, making it easier for practitioners to plan their change efforts sequentially. Public sector managers can apply these research results to craft packages of policies addressing multiple practices at a time while accounting for their causal interconnections. Industry-specific insights provide opportunities for industry groups to work towards creating focused guidelines for implementation specific to their unique business contexts. Altogether, such a framework of priorities allows managers to progress beyond ad hoc initiatives for sustainability towards systemic, strategy-based approaches that understand the interlinked nature of SCP practices towards consumption and, ultimately, the efficient execution of the goal of SDG 12 for India.

This research contributes several significant advances to the theory of sustainability and methodology. It develops a theoretical understanding of SCP practices for sustainable consumption and production through a hierarchical framework for identifying the causality of SCP practices, advancing beyond conventional approaches that isolate sustainability practices as independent entities. It expands SCP literature by illustrating how applying Grey theory can successfully manage the ambiguity and subjectivity of sustainability scores, especially for developing economy contexts where data may be incomplete, vague, or even conflicting. Merging the applications of Grey Delphi with Grey DEMATEL methodology constitutes a methodological advancement that improves the quality of multi-criteria decision-making within research on sustainability, providing a model for applying similar studies elsewhere and for other SDGs. It contributes to the theory of systems within sustainability through empirical validation of the interdependent nature of SCP practices, affirming Bengtsson et al.'s [5] position that consumption and transformation of production systems require changes along multiple dimensions. Cause-effect classification contributes to transition theory by identifying focal points within complex socio-technical systems through which interventions can speed up transitions toward sustainability. Additionally, the research addresses the theoretical gap between global sustainability goals and context-specific implementation strategies by providing a structured framework tailored to India's unique socio-economic landscape. The prominence-net effect matrix introduced in this study offers a novel theoretical construct for conceptualizing sustainability practices' relative importance and influence, extending existing sustainability assessment frameworks. Overall, this research advances the theoretical understanding of operationalizing abstract SDG targets into concrete, prioritized action plans while accounting for the complex interactions among diverse sustainability practices in emerging economy contexts.

7. Conclusion and future scope

This study has successfully prioritized sustainable consumption and production practices for achieving SDG 12 in India using an integrated Grey Delphi and Grey DEMATEL approach, providing valuable insights for policymakers and practitioners. The findings revealed that implementing circular economy practices, fostering multi-stakeholder partnerships, and adopting life cycle assessment approaches are primary drivers with the highest prominence and influence across the system. In contrast, sustainable supply chain management, consumption education, urban planning, and procurement practices function as effect group practices that benefit from improvements in driver practices. This causal framework enables the strategic allocation of resources by focusing on high-leverage intervention points within India's complex socio-economic landscape. Future research could extend this work by incorporating quantitative measures of implementation costs and benefits, developing sector-specific implementation roadmaps, examining temporal dimensions of practice implementation, and exploring synergies between SDG 12 and other Sustainable Development Goals in the Indian context. Additionally, comparative studies across different developing economies could identify transferable lessons and context-specific challenges, while action research involving key stakeholders could translate these theoretical insights into practical implementation strategies tailored to India's diverse regional contexts. Future researchers can also discuss how integrating Markov chains or dynamic MCDM extensions can capture evolving policy effectiveness and temporal spillovers.

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Neha Gupta: Writing – review & editing, Software, Methodology, Formal analysis, Data curation. **Srikant Gupta:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Example 1 — Grey Delphi (worked example)
Using the linguistic scale given in Table 3.
Step 1 — Expert responses for a practice.
Suppose k = 5 experts evaluated Practice P_x and gave these linguistic ratings:
Expert 1: VHI → [3, 4]
Expert 2: HI → [2, 3]
Expert 3: VHI → [3, 4]
Expert 4: LI → [1, 2]
Expert 5: HI → [2, 3]
Step 2 — Aggregate the grey interval (component-wise sum and average).
Sum of lower bounds = 3 + 2 + 3 + 1 + 2 = 11
Sum of upper bounds = 4 + 3 + 4 + 2 + 3 = 16
Average (divide by k = 5):
Lower average = 11 / 5 = 2.2
Upper average = 16 / 5 = 3.2
So, the aggregated grey interval for P_x is:

$$\widetilde{H}_{P_x} = [2.2, 3.2]$$

Step 3 — Whitenisation (crisp value).
Using equal-weight mean whitenisation (β = 0.5):
$\widetilde{H}^* = \beta \cdot H_{\text{upper}} + (1-\beta) \cdot H_{\text{lower}} = 0.5 \times 3.2 + 0.5 \times 2.2 = \frac{3.2+2.2}{2} = 2.7$
So, the crisp (whitened) value for P_x is 2.7.
Step 4 — Threshold check.
If the acceptance threshold is λ = 3.5 (as in the manuscript), then:
2.7 < 3.5 → **P_x would be excluded** (not accepted) after Delphi.
Example 2 — Grey DEMATEL (worked example with 3 practices)
This example demonstrates the DEMATEL arithmetic after grey → whitened (crisp) conversion. For clarity we show a 3-practice system {A, B, C}.
Step 1 — Suppose after grey conversion & whitenisation you obtain the following **crisp direct-relation matrix** X(rows = influencer, columns = influenced):

$$X = \begin{bmatrix} 0 & 2.50 & 1.50 \\ 1.00 & 0 & 2.00 \\ 0.50 & 1.00 & 0 \end{bmatrix}$$

(Each non-diagonal entry is the whitened score representing how strongly row-practice influences column-practice, aggregated across experts.)
Step 2 — Normalize the direct-relation matrix.
Compute row sums of X:

- Row A sum = 0 + 2.50 + 1.50 = 4.00
- Row B sum = 1.00 + 0 + 2.00 = 3.00
- Row C sum = 0.50 + 1.00 + 0 = 1.50

Let $s = 1/\max(\text{row sums}) = 1/4.00 = 0.25$.
Normalized matrix $N = s \cdot X$:

$$N = 0.25 \times \begin{bmatrix} 0 & 2.50 & 1.50 \\ 1.00 & 0 & 2.00 \\ 0.50 & 1.00 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0.625 & 0.375 \\ 0.25 & 0 & 0.50 \\ 0.125 & 0.25 & 0 \end{bmatrix}$$

Step 3 — Compute total relation matrix T.
Use the formula $T = N(I-N)^{-1}$. Computing T (matrix arithmetic shown here as results):

$$T \approx \begin{bmatrix} 0.4359 & 1.1795 & 1.1282 \\ 0.5128 & 0.5641 & 0.9744 \\ 0.3077 & 0.5385 & 0.3846 \end{bmatrix}$$

Step 4 — Compute row sums r_i and column sums c_j (total outward and inward influences):

- r = row sums of T:
  - $r_A = 0.4359 + 1.1795 + 1.1282 = 2.7436$
  - $r_B = 0.5128 + 0.5641 + 0.9744 = 2.0513$

  - $r_C = 0.3077 + 0.5385 + 0.3846 = 1.2308$
- c = column sums of T:
  - $c_A = 0.4359 + 0.5128 + 0.3077 = 1.2564$
  - $c_B = 1.1795 + 0.5641 + 0.5385 = 2.2821$
  - $c_C = 1.1282 + 0.9744 + 0.3846 = 2.4872$

Step 5 — Prominence (P) and Net effect (E):

- Prominence $P_i = r_i + c_i$:
  - $P_A = 2.7436 + 1.2564 = 4.0000$
  - $P_B = 2.0513 + 2.2821 = 4.3333$
  - $P_C = 1.2308 + 2.4872 = 3.7179$
- Net effect $E_i = r_i - c_i$:
  - $E_A = 2.7436 - 1.2564 = +1.4872$
  - $E_B = 2.0513 - 2.2821 = -0.2308$
  - $E_C = 1.2308 - 2.4872 = -1.2564$

Step 6 — Interpretation and classification.

- If $E_i > 0$ then practice i is a net cause (driver).
- If $E_i < 0$ then practice i is a net effect (receiver).

From the results:

- A: $E_A = +1.4872$ → Cause / driver
- B: $E_B = -0.2308$ → Effect / receiver
- C: $E_C = -1.2564$ → Effect / receiver

Prominence values show overall involvement; B has the highest prominence here (4.3333), meaning it is highly connected, even though its net effect is slightly negative (i.e., it receives slightly more influence than it gives).

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