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To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP

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A B S T R A C T

With increasing globalization and digitalization, agricultural organizations have started changing their business processes. Agri-organization has begun to adopt technologies to get a more sophisticated, customer-centric, and sustainable supply chain. Although the introduction of interconnected new technologies and the concept of circular economy (CE) present numerous challenges, it has proved its value in the industrial sector to achieve a sustainability target. This study identifies Industry 4.0 (I4.0) and CE adoption barriers in the agriculture supply chain (ASC) in India. The study was extended to ascertain the contextual relationship among the barriers and to prioritize them with respect to one another. The 11 barriers with their key elements were enlisted after thorough literature analysis and interaction with experts. The barriers were modeled through an integrated ISM-ANP approach. The study indicates that lack of government support and incentives and lack of policies and protocols are significant obstacles to implementing the I4.0-CE model. The findings of the current research work will be beneficial for the agri supply chain stakeholders in preparing the strategic deployment of I4.0-CE.

1. Introduction

The yearly wastage of 1.3 billion tons of food is causing a loss of USD 2.6 trillion that could have been used to feed 815 million people around the world. Approximately 14 percent of agricultural goods are lost during transport and storage after harvesting at various stages of SC (FAO, 2019). An increase in food wastage has drawn the attention of the 'agriculture supply chain (ASC)' practitioners towards the adoption of circular economy practices to build a competitive market for sustainable agricultural goods on a global scale. As the role of agricultural commodities in daily life has made ASC a vital subject, organizations are trying to implement different technologies to reduce food wastages and stay in the competitive market. ASC incorporates "supply chain management (SCM)," production and demand management to fulfill the consumer's requirement (Chandrasekaran and Raghuram, 2014). As the behavior of consumers is changing with growing awareness, Handayati et al. (2015) suggested that organizations change their value-creation approach. To meet the consumer's requirements, ASC practitioners have started pushing their business towards digital transformation and forming alliances with farmers to enable sustainable practices. The aim is to decrease the impact of the supply chain (SC) upon the ecosystem (Fu et al., 2017). Industry 4.0 (I4.0) is one such technique that is trending in terms of adoption, ever since its introduction in 2011. This transition of ASC can also be seen through digitalization and adoption of technologies like Internet of things (IoT), Cyber-physical system (CP), Cloud Computing (CC), Big-data and other technologies associated with I4.0 (Yadav et al., 2020a).

I4.0 is the integration of smart technologies that enable digitalization in the process of SC (Lasi et al., 2014; Oesterreich and Teuteberg, 2016). It has been considered as a concept to enhance product quality (Tortorella and Fettermann, 2017) and decentralize the decision-making process by providing more green flexibility

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(Moeuf et al., 2017; Bai et al., 2017). The accomplishment of I4.0 in SC can increase transparency and visibility, and enable real-time data capturing (Hofmann and Rüsch, 2017). It can be used to track agri products throughout the ASC and allow the CE model to fit (Casado-Vara et., 2018). According to Banerjee (2019), the adoption of IoT and blockchain technology will bring a revolutionary change in ASC by addressing issues like trackability, farmer availability and authenticity. Applications of I4.0 technology for sustainable growth continue to draw growing interest from researchers and professionals who can maximize the global effect of technology on CE through its supply chain activities and services (Bai et al., 2020). In spite of the several benefits of adopting Industry 4.0 at each stage of ASC, million tons of agriculture products are wasted and lost every year due to poor management practices (Chauhan et al., 2019). As technology adoption is not sufficient in preventing food losses, FAO (2020) promoted the principle of CE to address this challenge in ASC.

The concept of CE has gained more popularity after its inclusion in the “Sustainable Development Goals (SDGs),” by the United Nations (UN general assembly, 2015). Circular economy is the concept that promotes maximum use of resources through “recycling, reuse and recovery” methods (Luttenberger, 2020). CE provides a unique perspective on the operational and administrative structures for the recovery of the used and waste goods. Its efficiency and effectiveness have become significant elements in turning conventional business models into more sustainable ones (Ghisellini et al., 2016; Geissdoerfer et al., 2017). The concept of integrating I4.0 and CE has not been explored thoroughly, but it can be pushed effectively in SC with an effective plan and strategy (Lopes de Sousa Jabbour et al., 2018). CE should be applied based on strategic and policy-oriented processes in order to build efficient consumer products using the resources of I4.0 (Pham et al., 2019). Adoption of I4.0 and CE with appropriate “information sharing strategy” would help in achieving operational excellence (for example diffusion and redistribution of recycled products, product return, product reuse etc.) in supply chain operations (Dev et al., 2020). This integration would help in the sustainable technological growth of organizations for various positive outcomes in terms of profit-making and environmental conservation as well. However, acceptance of CE demands cooperation from producers, suppliers and individual customers. The integration of technologies with CE in ASC can make the process of recycling and recovery more productive and environment-friendly (De Corato, 2020). The adoption of smart technologies with CE will enable visibility, reliability, trackability and trust among all stakeholders, but it would also lead to a high financial burden on the organization. Implementation of the CE concept to obtain the goal of sustainability in ASC may cause social, economic and environmental challenges (Kamble et al., 2020). India, where 70% of the population still relies on the agricultural sector, which is the primary producer of pulp, milk and jute and the second-largest producer of rice, sugar cane, wheat, cotton, vegetables and fruit, has also raised significant sustainability concerns. To fulfill the demand of a rising population, India needs to adopt green or sustainable practices (Mangla et al., 2020). Although there is a study related to I4.0-CE in the Indian context related to the automobile sector (Yadav et al., 2020a), ASC risk management using CE (Yazdani 2019) and IoT adoption in ASC (Yadav et al., 2020b), it is essential to develop and plan the strategy of adopting I4.0-CE in the agriculture sector to overcome the challenges of transformations. Thus, an investigation was carried out to find the adoption barriers against I4.0-CE to strengthen the sustainable future of organizations in ASC. More precisely, this study attempts to achieve the following research objectives (RO):

RO1: To identify Industry 4.0 and CE adoption barriers in ASC.

RO2: To find the contextual relationship among barriers identified in RO1, and.

RO3: To prioritize each barrier with respect to its significance.

The modeling of these barriers yields a statistically supported level of hierarchy that will help in strategy development. An analytical network process (ANP) is used to ascertain the priorities of barriers, which would provide further insights into their relative significance. The remainder of the manuscript is organized as follows: Section 2 describes the literature review of I4.0, ASC and CE with especial stress on the research tools employed. In section 3, the research methodology employed in the present work is discussed. In section 4, data collection and data analysis are presented. The discussion, implications and unique contribution of the research have been outlined in section 5, while the conclusion is discussed in section 6.

2. Conceptual background

A comprehensive analysis of articles published in the Web of Science and Scopus was undertaken to gain insights about the adoption of I4.0 for CE in ASC. The search was restricted to the English language and to journal articles only. Also, the time period was set between 2016 and 2020 to ensure the collection of only the latest data. The search was carried out with the keywords ‘Industry 4.0 challenges’ OR ‘Industry 4.0 adoption’ OR ‘Industry 4.0 implementation’ AND ‘circular economy’ AND ‘agriculture supply chain’ or ‘Agri supply chain’. After removing the duplicates from the database. 152 articles were initially chosen. After abstract analysis, 43 articles were finally selected for this study. All the selected articles were divided into five sub-sections for further review (1) Industry 4.0 adoption in ASC (2) Industry 4.0 adoption for CE (3) Industry 4.0 and CE in ASC (4) Barriers in implementing Industry 4.0 & CE in ASC and (5) Tools and techniques.

2.1. Industry 4.0 adoption in ASC

I4.0 has brought a disruptive change in the logistics sector by altering the business model and implementing technologies in different SC processes. I4.0 enabled SC can integrate various services as per requirement to increase the responsiveness and flexibility of the SC network (Xu et al., 2018). Long et al. (2016) reported socio-economic challenges in adopting technological innovation for ASC while Long et al. (2019) explained the need for social, ethical and technological transition to accept society to get the maximum benefit of new technology in ASC. Yadav et al. (2020c) explained the adoption of I4.0 in ASC as a transition that may take years to get digitalized and accepted by stakeholders. Lezoche et al. (2020) mentioned product, process, market, and environment as the major uncertainties of ASC that could be reduced by adopting the concept of Industry 4.0 with technologies like IoT, Blockchain, Bigdata and Artificial intelligence.

2.2. Industry 4.0 adoption for the circular economy

The ‘fourth industrial revolution’ or I4.0 has gained ample attention in several sectors during the past few years. Integration capabilities, real-time data tracking, data capturing, and reconfiguration ability that support the sustainability aspect have made it more accessible (Liao et al., 2017). It has contributed to improvement in the quality of production and distribution networks and has also created adverse environmental effects from excessive use. Researchers often raise concerns such as whether the adoption of I4.0 will drive circular economy deployment (Tseng et al., 2018). Ghobakhloo (2020) and Liboni et al. (2018) highlighted that the acceptance of I4.0 would contribute positively to refining CE for reusability, recycling and remanufacturing by integrating technology and closing loopholes. Rajput and Singh (2019) explored the relationship between I4.0 and CE and identified challenges restricting the implementation of I4.0. de Sousa Lopes de Sousa Jabbour et al. (2018) mentioned that value creation and its capturing through I4.0 has become essential to achieve CE as it seeks continuous improvement by measuring the performance and routine checkup of the process (Nascimento et al., 2019). If the organization has knowledge sharing and adoptive programs, the adoption of I4.0 will be more beneficial (Luz et al., 2020) and will also satisfy the sustainability aspect of organizations (Ranieri et al., 2020). Yadav et al. (2020a) proposed 22 solution measures concerning 28 identified barriers against adopting I4.0 and CE; they recommended to develop a structural relationship among challenges to get more insights. The result obtained while hypothesis testing by Brozzi et al. (2020) revealed that most of the companies did not perceive the adoption of I4.0 as a beneficial concept for achieving sustainability.

2.3. Industry 4.0 and circular economy in ASC

Owing to excess waste production at each phase of the 'product life cycle (PLC),' the definition of CE has generated considerable attention from academicians and practitioners in enhancing sustainability and reducing waste. There is an immense amount of literature linked to I4.0 or CE concerning ASC, but research about I4.0, CE and ASC together is limited. Tseng et al. (2019) described the idea of CE as a strategy to improve the ecological aspect of ASC by enhancing the quality of the operation. It was advised to integrate I4.0 and CE to improve the productivity and SC security issues. Yazdani et al. (2019) explained CE as a critical strategy for the effective consumption of resources and reducing ASC risks. Belaud et al. (2019) proposed a method to adopt I4.0 into ASC to reduce agricultural waste and enhance sustainability. During the same period, Kaur (2019) explained that the adoption of CE in ASC using IoT would improve food security by increasing visibility. The study of Klerkx and Rose (2020) demonstrated the potential benefits of the use of technology in ASC that would bring significant changes in traditional practices of food manufacturing and food retailing.

2.4. Industry 4.0 and CE barriers for ASC

The growing idea of I4.0 and CE is up-and-coming in reducing the environmental impact of business. Technology related to I4.0, like the cyber-physical system, IoT, Bigdata, etc. have the capabilities to stay connected and provide critical information throughout the life cycle of products (Alcayaga et al., 2019). The author explained the convergence of CE and technologies as a smart-circular strategy that may reduce the implementation gap of CE through smart remanufacturing, smart reuse, smart recycling, and smart maintenance. Luthra and Mangla (2018) reported that the adoption of I4.0 for sustainable SC poses organizational, strategic, technological, and ethical and legal threats and highlighted 18 critical challenges faced by the sustainable manufacturing sector. Lack of global standards and data sharing protocols, lack of government support and policies, and financial constraints are the most significant issues restricting the acceptance of I4.0. Kirchherr et al. (2018) highlighted the cultural, technological, market and regulatory challenges obstructing CE adoption. It was discussed that the low rate of virgin material in the market, adoption cost of CE, and the absence of financial subsidies are the significant barriers in implementing the CE concept. Liboni et al. (2018) pointed out the challenges encountered by industries to achieve I4.0 and to fulfil the objectives of environmental protection. The study emphasizes the importance of technology integration to enable the capabilities of reuse, remanufacturing and recycling. Barriers were highlighted in terms of "cultural aspect", "economic aspect", and "technological and legal aspect." Rajput and Singh (2019) identified the I4.0 barriers against CE adoption through discussion with experts and literature review. The analysis indicates that "process digitalization," "infrastructure standardization" and "semantic interoperability" are the dominating barriers that can impact the integration of I4.0- CE. Sharma et al. (2019) mentioned that the execution of CE in ASC is facing issues due to lack of technology and technique, poor government policies, and lack of farmer's awareness. Kumar et al. (2019) highlighted the environmental, government/political, infrastructural, financial, technological, and legal challenges faced by the food supply chain to implement sustainability. Yadav et al. (2020) identified sustainable SC issues and presented their solution procedures based on I4.0-CE adoption. Lack of availability of financial support, technological and human resources, conflicts among sustainability policies, poor management commitment for adoption of sustainability and free trade provisions were the most significant issues reported in the study. Yadav et al. (2020c) pointed regulatory uncertainty or the lack of government regulation and public perception or lack of trust among stakeholders as critical barriers against implementing blockchain in Indian ASCs. The details of identified key barriers through literature review have been listed in Supplementary (see Table 1 in Supplementary).

2.5. Research tools and techniques

In the literature, the Multi-Criteria Decision-Making technique and survey method were the broadly used ones employed to study the factors, challenges and barriers. A brief detail of the tools and research methods employed in the previous research works related to I4.0, ASC and CE is provided in Table 1.

2.6. Findings of the literature review

From the literature review, it was observed that CE and I4.0 have great potential to bring transformation in ASC. The transition needs the development of a theoretical foundation for implementing I4.0-CE. Based on a review of the literature, several research gaps related to I4.0- CE adoption in ASC have been identified below:

1. The study related to CE or I4.0 for ASC is widely reported in the literature. But the mixed review of these concepts for ASC is minimal. There is a growing need to study the influence of I4.0 and CE on food SC (Raut et al., 2019a,b) as the implementation of I4.0 and CE may create new challenges for ASC.
2. The concept of I4.0 and sustainable SC are complementary to each other and capable of reducing the implementation challenges for an automobile organization (Yadav et al., 2020). This opens the opportunity to explore the integration of different concepts with I4.0 to look for improvement in the agriculture sector as well.
3. The introduction of a new concept like agriculture 4.0 (Lezoche et al., 2020) and smart circular systems (Alcayaga et al., 2019) has provided future directions for researchers working in the ASC area. There are prospects for empirical and theoretical works related to strategy development, barrier identification, implementation process, etc.

The study gaps listed above suggest the need to define barriers relevant to I4.0 and CE for ASC in developing countries like India and to build a framework that demonstrates the interrelation between these barriers. It also demands prioritization to achieve the value or strength of each barrier.

Table 1
Research tools identified through literature review.

References	Purpose	Research theme	Tools, Techniques
Long et al. (2016)	Barriers identification	Technological Innovation, smart agriculture	Interviews, thematic analysis
Liboni et al. (2018)	For getting trends and challenges	Industry 4.0, environment protection & safety	Interviews, “soft system methodology (SSM)”
Kirchherr et al. (2018)	Barriers identification	CE	Semi-structured interviews, Survey
Luthra & Mangla (2018)	Challenge identification and prioritization	Industry 4.0, sustainability	AHP, Expert opinion, Explanatory factor analysis
Rajput & Singh (2019)	Development of contextual relation	Industry 4.0, CE	ISM
Kumar et al. (2019)	Challenge identification, inter-relation, and priority establishment	“Agri-food supply chain (A-FSC)”	Expert input, “Graph theory and matrix approach (GTMA)”
Ghobakhloo (2020)	Functions identification, inter-relation, and priority establishment	Industry 4.0 and sustainability	ISM
Sehnem et al. (2019)	Challenge identification	CE	Case Study
Sharma et al. (2019)	Challenge identification, inter-relation, and priority establishment	CE, FSC	Delphi, ISM
Yazdani et al. (2019)	Drivers identification	CE, ASC	Failure mode and effect analysis, Step-wise Weight Assessment Ratio Analysis,
Yadav et al. (2020)	Framework development (challenges and solution measure identification)	Industry 4.0, CE, sustainable supply chain	Elimination and Choice Expressing Reality, Best Worst Method
Joshi et al. (2020)	Factor identification	A-FSC, sustainability	Semi-structured interview, “principal component analysis (PCA)”
Yadav et al. (2020)	Barriers identification	ASC, blockchain	Delphi, ISM, Fuzzy- MICMAC

3. Research methodology

In this study, the adoption barriers of I4.0-CE in ASC were demonstrated using a three-phase hybrid research methodology. In the first phase, existing literature was reviewed and analyzed with one round of Delphi study to identify essential barriers influencing I4.0-CE adoption in ASC. The second phase incorporated ISM to yield the hierarchical structure or inter-relationship between the identified barriers. The ANP approach was used to evaluate the importance of the barriers in the last phase of the study. The complete roadmap of the research methodology is shown in Fig. 1.

3.1. Phase-I: delphi technique

The Delphi technique is an organized, iterative procedure, with anonymous assessments and systematic enhancement, to get a collective opinion from experts coming from diverse domains (Linstone and Turoff, 1975). Delphi helps to relieve the impact of an influential person to produce a more accurate and more informed judgment (Green and Price, 2000; Tersine and Riggs, 1976). In the SC domain, the Delphi method is widely used by researchers to study various problems. It was used with TOPSIS to evaluate location selection factors (Yen et al., 2017) and with fuzzy clustering for the application of “big data analytics” in SC operations (Roβmann et al., 2018). Delphi, along with DEMATEL, was used in the textile and apparel SC to enlist the critical challenges against achieving the sustainable goals (Gardas et al., 2018). The method was also used to explore sustainability indicators for food manufacturers (Ahmad and Wong, 2019) and to get better insights about how CE was creating a transition path towards sustainability (de Jesus et al., 2019).

3.2. Phase-II: interpretive structural modeling

ISM is a well-known approach proposed by Warfield (1974), to identify the relationship between different factors with their hierarchical structure. The processes involved in ISM are explained below:

ISM Step-1: It starts with the identification of attributes for specific problems or issues whose interactions are to be developed.

ISM Step-2: A relative relation is determined between the attributes relating to the pairs of variables modeled.

ISM Step-3: After identifying the factors, a contextual relation called structural self-interaction matrix (SSIM) is established. The matrix can be explained as follows:

$$W = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_m \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \dots & c_n \end{array} \\ \begin{bmatrix} 0 & \sigma_{12} & \dots & \sigma_{1n} \\ \sigma_{21} & 0 & \dots & \sigma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m1} & \sigma_{m2} & \dots & 0 \end{bmatrix} \end{array} \quad \text{(eq. 01)}$$

Where c_i signifies the i^{th} factors σ_{ij} indicates the interrelationship among the i^{th} and j^{th} factors and W symbolize the SSIM. The developed SSIM matrix is filled by industry experts using these symbols:

- V: shows the link from i to j (attribute i will help reach attribute j).
- A: shows the link from j to i (attribute j will help reach attribute i).
- X: is used to show bi-directional relation between $i$and j (attribute i and j will help get each other).
- O: shows no link among i to j.

There may be a difference in the view of experts regarding the linkages between two attributes. To confirm that the linkages contain only the crucial attributes, the technique is resumed till all the experts approve the direction of the linkages.

ISM Step-4: From SSIM, initial reachability matrix (IRM) is established by substituting “V”, “A”, “X” and “O” of SSIM using the following binary rules:

- If $(i,\ j)$ in “SSIM” is assigned with symbol “V”, then $(i,\ j)$ replaced by 1 and $(j,\ i)$ replaced by 0.

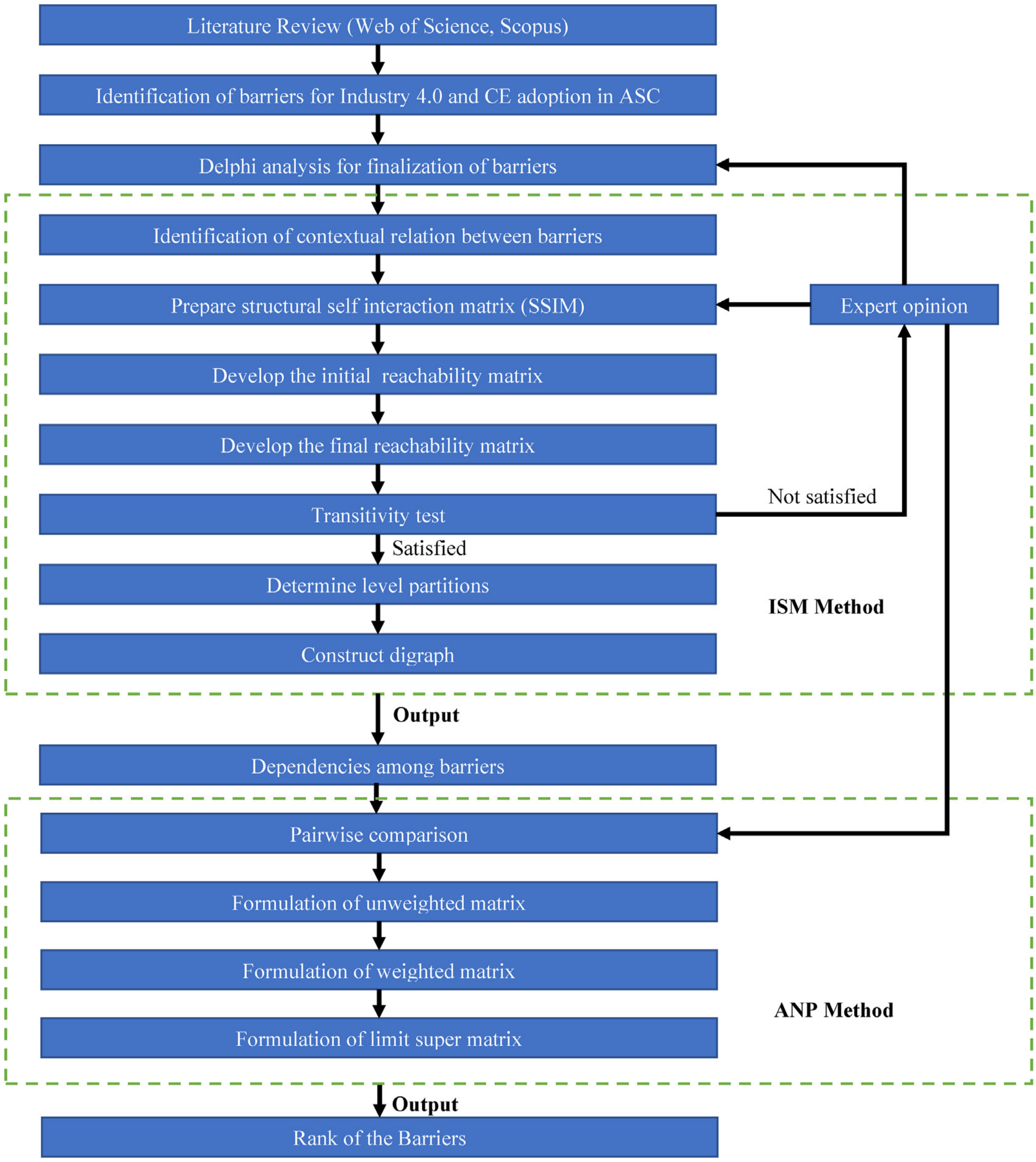

Fig. 1. Roadmap of present research work.

- If (i, j) in "SSIM" is assigned with symbol "A", then (i, j) replaced by 0 and (j, i)replaced by 1.
- If (i, j) in "SSIM" is assigned with symbol "X", then $(i, j)$and (j, i) replaced by 1.
- If (i, j) in "SSIM" is assigned with the symbol "O", then (i, j) and (j, i) replaced by 0.

ISM Step-5: Final reachability matrix is achieved by using Boolean multiplication and addition of the set theory. The inference arises due to multiple indirect linkages that are eliminated by the transitivity concept, i.e., if p →q (p is linked to q) and q →r (q is linked to r), it may be inferred that p → r (p is linked to r).

ISM Step-6: Using the reachability set (RS), antecedent set (AS), and final reachability matrix of attributes, the level partitions are done. The RS for an attribute constitutes the element present in the row with the value of "1" including factors itself. The AS for an attribute constitutes the element present in the column with the value of "1" including the attribute itself. Then, the intersection set (IS) is identified by selecting the same elements from the AS and RS. The attribute for the RS and IS is the same, occupying top position in the ISM model. The elements that occupy the top position have been separated from other list and a similar process is continued to obtain the position for other elements.

ISM Step-7: A digraph is obtained from the final reachability matrix. In this method, the top-position element is placed at the top of the digraph, and the second positioned elements are placed next to and so on until all elements are used. Then, as per the driving and dependence power, elements can be classified into four clusters using MICMAC.

3.3. Phase-III: analytical network process

The ANP is the developed form of AHP (Saaty, 1996) that is generally used to rank the factors having bi-directional relations. As compared to AHP, the ANP technique has the benefit of prioritizing sets of items, considering unidirectional, bidirectional, dependency, and the independency of the items (Chen et al., 2019). The AHP method is best suited for linear relations and cannot be used for network structure. Apart from AHP, DEMATEL has been widely used for establishing the cause-and-effect relation based on the determined weight of the items and integrated with ANP or AHP to ascertain the priority of the items (Li et al., 2020). The weight obtained from DEMATEL is only used for finding the interaction of the item but fails to give the actual rank or priorities of the item (Yi et al., 2021). In this study, initially, a pair-wise matrix, also called a supermatrix, is formulated that represents the importance of one attribute in the network on the other characteristic. Suppose a system of *n*attributes; component *p* indicated by $c_{p,}$ $p = 1, 1\ldots N$, has N_p element that indicates $e_{h1}e_{h2}\ldots e_{h_{Nh1}}$; then, supermatrix will be derived as:

$$A = \begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \\ e_{11}\cdots e_{1n_1} & e_{21}\cdots e_{2n_2} & & e_{n1}\cdots e_{nn_N} \end{array} \\ \begin{array}{c} c_1 \begin{array}{c} e_{11} \\ \vdots \\ e_{1n_1} \end{array} \\ c_2 \begin{array}{c} e_{21} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots \\ c_n \begin{array}{c} e_{n1} \\ \vdots \\ e_{nn_N} \end{array} \end{array} & \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} \end{array} \quad \text{(eq. 02)}$$

By doing the pairwise assessment, a priority vector is obtained, which represents the influence of a given set of attributes on another attribute in the system. When an attribute has no impact on another, the assigned value should be zero (Saaty, 1996). For example, the matrix with three levels of hierarchy is given by:

$$A = \begin{bmatrix} I & A_{12} & 0 \\ A_{21} & 0 & 0 \\ 0 & A_{32} & I \end{bmatrix} \quad \text{(eq. 03)}$$

Where vectors A_{12}, A_{21} and A_{32} represent the influence of the factor, *I*is the identity matrix, and *A* is the supermatrix. Overall significances of factors is illustrated as per the Cesaro Sum rule (Saaty and Vargas, 2013) to bring up the supermatrix to limiting powers, $A^{\infty} = \lim_{k\to\infty} (1/N)a_j^k$ because it converges to a unique limit column vector ($A^{\infty} = A^{\infty} \times e^T$) and gives the desired priorities. Still, if *A* can be simplified, then the q_i of the "principal eigenvalue" must be measured to get the limit priorities of a simplified stochastic matrix (Chang et al., 2013). For example, $q_i = 1$, A^{∞} for a hierarchy with 3 stages is given as follows:

$$A^{\infty} = \lim_{k\to\infty} \begin{pmatrix} 0 & 0 & 0 \\ A_{22}^k A_{21} & A_{22}^k & 0 \\ A_{32} \sum_{p=0}^{k-2} A_{22}^p & A_{32} \sum_{p=0}^{k-1} A_{22}^p & I \end{pmatrix} \quad \text{(eq. 04)}$$

If, $|A_{22}| < 1$ infers that $(A_{22})^k \to 0$, as $k \to \infty$, so:

$$A^{\infty} = \lim_{k\to\infty} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ A_{32}(I - A_{32})^{-1} A_{21} & A_{32}(I - A_{22})^{-1} & I \end{pmatrix}$$

4. Data analysis

The research was conducted in three phases.

Phase 1: In the first phase, one round Delphi study was carried out to gather the information and conceptual understanding related to the identified barriers. The literature's identified barriers were discussed with practitioners and classified into 11 critical barriers and their sub-barriers based on the experts' opinion. The experts were selected from different government and private organizations by applying the Delphi technique for validations. The demographic profile of experts and common questions asked during the discussion are presented in the Supplementary (see Tables 2 and 3 of Supplementary).

Phase 2: Based on the proposed barriers identified from Phase1, questionnaires were prepared. A short summary and definition of each barrier was provided in the questionnaires to help the respondents. This data was collected in a specific format as per the ISM methodology.

Phase 3: After obtaining the relationship between the barriers, another set of questionnaires was prepared for collecting data for the third phase. Data was raised in the form of relative weight for each pair of barriers as per the standard rule used for ANP.

4.1. Phase I: delphi analysis

Step 1: All the identified barriers from literature (see Table 1 of Supplementary) were discussed with industry experts for formulating the final list of barriers. These barriers were categorized into 11 critical barriers, with their critical elements through expert interviews in Table 2. Under each barrier, there were critical elements associated with it and could be considered sub-barriers. The considered sub-barriers are industry-specific and categorized based on expert suggestions.

4.2. Phase II: ISM modeling

Step 2: Now, pairwise comparison was made by experts to obtain the contextual relationships among all the barriers.

Step 3: Development of SSIM as per eq 0.1 (seeTable 3).

Step 4: Conversion of SSIM into the "initial reachability matrix," (Table 4).

Step 5To obtain the "final reachability matrix", the "initial reachability matrix" undergoes a transitivity check (Table 5).

Step 6:Identification of IS and level partition (Table 6).

Step 7: In this step, the structural model was established with the help of the level of partitions. The relationship between different barriers is shown through connected arrows. The generated diagram is called a digraph or ISM model. Fig. 2 shows the linkages and level partition of different barriers, but it is still unclear which are the dependent barriers and which are the independent ones. To get a clear understanding of dependent and independent barriers, the MICMAC analysis was performed. All the identified barriers were categorized into four clusters based on their dependence and driver power (Fig. 3). The analysis shows that many barriers have the same driving power or dependence power and are placed at the same level in the ISM model. This might be infeasible or can create confusion for practitioners during decision making. Hence, to prioritize the selected barriers, the method of the analytical network process is employed as ISM is not suitable to obtain the ranking (Chang et al., 2013).Fig4.

4.3. Phase III: ANP analysis

Step 8: In this step, the methodology of ISM was utilized for establishing the ANP model, as shown in Fig4. The result of IRM and

Table 2
Proposed barrier after one round Delphi.

Barriers	Sub-barriers	Descriptions	References
Lack of awareness (LAW)	Unclear benefit, low understanding, the poor vision of the organization, low awareness of sustainable raw material, awareness of farmers	There is a need to understand the importance of I4.0 for accomplishing the goal of CE in ASC. Despite the rich volume of research works related to I4.0, CE and ASC, practitioners are still unaware and unfamiliar with these terms.	Long et al. (2016); Perales et al. (2018); Sharma et al. (2019) Brozzi et al. (2020)
Lack of generalized framework (LGF)	Global standards, protocols, integrated platforms, no universal consensus	Organizations are facing problems in the effective implementation of I4.0 due to the unavailability of globally accepted processes. Lack of a verified framework has become a significant concern for ASC practitioners.	Long et al. (2016); Luthra & Mangla (2018); Rajput & Singh (2019); Yadav et al. (2020c); Yadav et al. (2020a)
Lack of skilled workforce and digital environment (LSW)	Skilled workforce, Digital culture, Language barriers, process digitalization	Less technical skills and knowledge in the workforce to run and understand the technologically advanced systems. No digital platform and resources to provide training services necessary for the adoption of I4.0 -CE in ASC.	Long et al. (2016); Luthra and Mangla (2018); Kumar et al. (2019); Rajput and Singh (2019); Lezoche et al. (2020)
Lack of physical and IT infrastructure (LI)	Sensor integration, infrastructure standardization, interface platform, compatibility issues	No suitable infrastructure to the established connection between the physical and digital world. The conventional structure is not appropriate for a modern concept.	(Lezoche et al., 2020; Rajput and Singh, 2019)
Lack of competency and motivation (LCM)	Competitiveness, capability, fewer priorities to CE practices	No competition in the market in terms of environmental performance. Less motivation due to the lack of incentives for better sustainability programs and skills.	Luthra & Mangla (2018)
Lack of government support and incentives (LGS)	Legal issues, collaboration issues, unavailability of financial support, low price of virgin material	No government incentives, financial subsidies, and training programs to lower the adoption cost. Unavailable policy and protocol for CE and technology adoption.	(Kirchherr et al., 2018; Kumar et al., 2019; Yadav et al., 2020a)
Lack of sustainable practices (LCP)	Lack of compliance, sustainability regulation	No foundational sustainability practices have been acquired by the ASC like lean, circular, green practices for upgrading into modern techniques. Low investigation of environmentally suitable practices.	Sehnem et al. (2019; Yadav et al. (2020a)
Lack of effective policy and protocol (LPP)	Semantic interoperability issues, a policy that supports CE transition, monitoring, Sustainability standard and regulations,	The unavailability of inline policies concerning CE in ASC restricts the entrepreneur to invest and generate business opportunities.	Long et al. (2016); Kirchherr et al. (2018); Long et al. (2019); Sharma et al. (2019)
Lack of acceptance (LA)	High investment cost, sustainability adoption cost, security issues, fear to lose business during the transformation phase, trust issues	High investment cost and no real example of financial feasibility, security issues with technologies are reducing the acceptance rate.	Liboni et al. (2018); Kumar et al. (2019); Yadav et al. (2020c); Yadav et al. (2020b)
Lack of circular design aspect (LCD)	Eco-innovation, eco-design, eco-efficient technologies	Lack of design of the product with aspects of redesigning, remanufacturing, regeneration, and restoration for developing CE business models due to inefficient technology and lack of digitalization	Kirchherr et al. (2018); Rajput and Singh (2019); Lahane et al. (2020);
Fear of change of culture (FCC)	Producer and consumers culture,	Farmers are always under the fear of change. Being financially unstable, modernization and the environment is not on their priority list. They do not believe in long-term payback and investment.	Liboni et al. (2018); Kirchherr et al. (2018); Yadav et al. (2020a)

Table 3
Datasheet of ISM.

Barriers	LAW	LGF	LSW	LI	LCM	LGS	LCP	LPP	LA	LCD	FCC
LAW		O	V	O	A	A	V	V	V	V	V
LGF			O	O	O	O	V	A	V	X	O
LSW				O	O	A	V	A	V	V	A
LI					V	A	V	A	V	O	O
LCM						A	X	A	X	A	O
LGS							V	V	V	V	V
LCP								A	X	A	A
LPP									V	V	V
LA										A	A
LCD											O
FCC											

Table 4
Initial reachability matrix.

Barriers	LAW	LGF	LSW	LI	LCM	LGS	LCP	LPP	LA	LCD	FCC
LAW	1	0	1	0	0	0	1	1	1	1	1
LGF	0	1	0	0	0	0	1	0	1	1	0
LSW	0	0	1	0	0	0	1	0	1	1	0
LI	0	0	0	1	1	0	1	0	1	0	0
LCM	1	0	0	0	1	0	1	0	1	0	0
LGS	1	0	1	1	1	1	1	1	1	1	1
LCP	0	0	0	0	1	0	1	0	1	0	0
LPP	0	1	1	1	1	0	1	1	1	1	1
LA	0	0	0	0	1	0	1	0	1	0	0
LCD	0	1	0	0	1	0	1	0	1	1	0
FCC	0	0	1	0	0	0	1	0	1	0	1

the result of MICMAC analysis was used for developing the ANP network. During ANP analysis, the independent barriers were not compared with any other barriers, and the rest of the pairwise comparison was performed by removing the transitivity link of FRM (Chang et al., 2013). Depending on the relationship between barriers, a pairwise comparison matrix was designed in the SUPER DECISION software based on data gathered from industry experts.Table 7.

Step 9: After all the questionnaires in the network were filled, i.e., once the relative weight was assigned as per eq. 02, an unweighted supermatrix using (see Table 7) representing the influence of each barrier on other barriers was built.Table 9.

Step 10: As there was no cluster or alternative, in this case, the unweighted and weighted supermatrix would be the same.

Step 11. In this step, the weighted supermatrix was converted into a limit supermatrix using eq 0.4, by raising its power until all the

Table 5
Final reachability matrix.

Barriers	LAW	LGF	LSW	LI	LCM	LGS	LCP	LPP	LA	LCD	FCC	Driver Power
LAW	1	1*	1	1*	1*	0	1	1	1	1	1	10
LGF	0	1	0	0	1*	0	1	0	1	1	0	5
LSW	0	1*	1	0	1*	0	1	0	1	1	0	6
LI	1*	0	0	1	1	0	1	0	1	0	0	5
LCM	1	0	1*	0	1	0	1	1*	1	1*	1*	8
LGS	1	1*	1	1	1	1	1	1	1	1	1	11
LCP	1*	0	0	0	1	0	1	0	1	0	0	4
LPP	1*	1	1	1	1	0	1	1	1	1	1	10
LA	1*	0	0	0	1	0	1	0	1	0	0	4
LCD	1*	1	0	0	1	0	1	0	1	1	0	6
FCC	0	0	1	0	1*	0	1	0	1	1*	1*	6
Dependence	8	6	6	4	11	1	11	4	11	8	5	

Table 6
Level partitions of barriers.

Barriers	RS	AS	IS	Level
LAW	LAW,LPP	LAW,LGS,LPP	LAW,LPP	VI
LGF	LGF	LAW,LGF,LSW,LGS,LPP	LGF	III
LSW	LSW	LAW,LSW,LGS,LPP,FCC	LSW	IV
LI	LAW,LI	LAW,LI,LGS,LPP	LAW,LI	III
LCM	LAW,LSW,LCM,LCP,LPP,LA LCD,FCC	LAW,LGF,LSW,LI,LCM,LGS,LCP LPP,LA,LCD,FCC	LAW,LSW,LCM,LCP,LPP LA,LCD,FCC	I
LGS	LGS	LGS	LGS	VII
LCP	LAW,LCM,LCP,LA	LAW,LGF,LSW,LI,LCM,LGS,LCP, LPP,LA,LCD,FCC	LAW,LCM,LCP,LA	I
LPP	LAW,LPP	LAW,LGS,LPP	LAW,LPP	VI
LA	LCM,LCP,LA	LAW,LGF,LSW,LI,LCM,LGS,LCP LPP,LA,LCD,FCC	LCM,LCP,LA	I
LCD	LAW,LGF,LCD	LAW,LGF,LSW,LGS,LPP,LCD,FCC	LAW,LGF,LCD	II
FCC	FCC	LAW,LGS,LPP,FCC	FCC	V

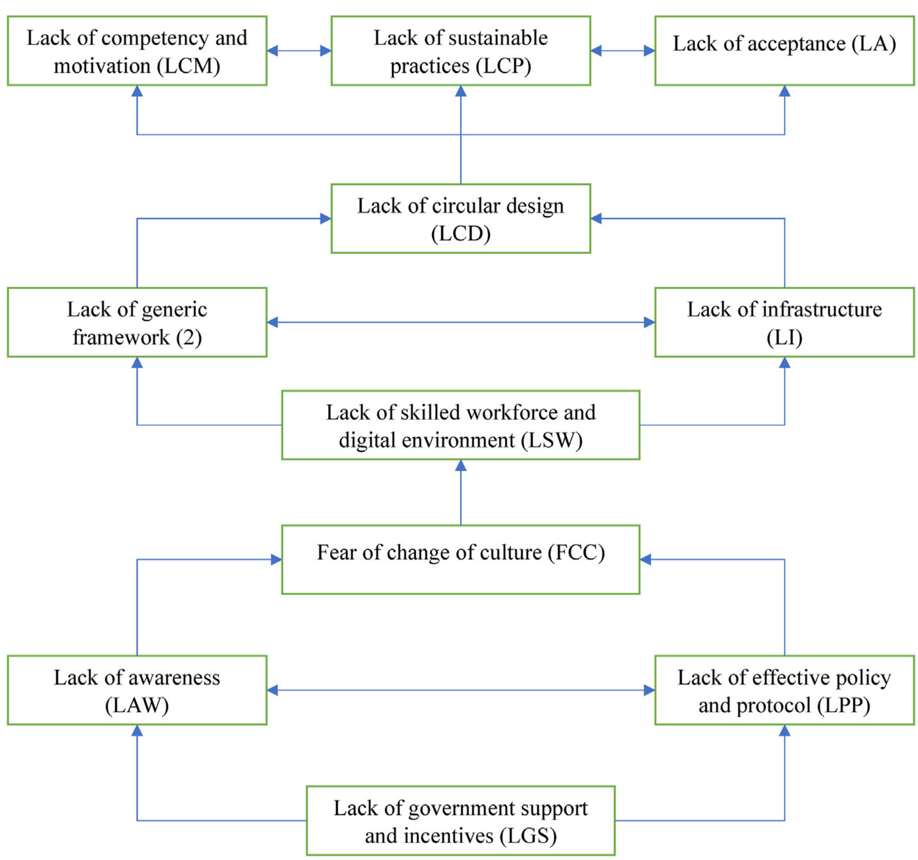

Fig. 2. ISM model.

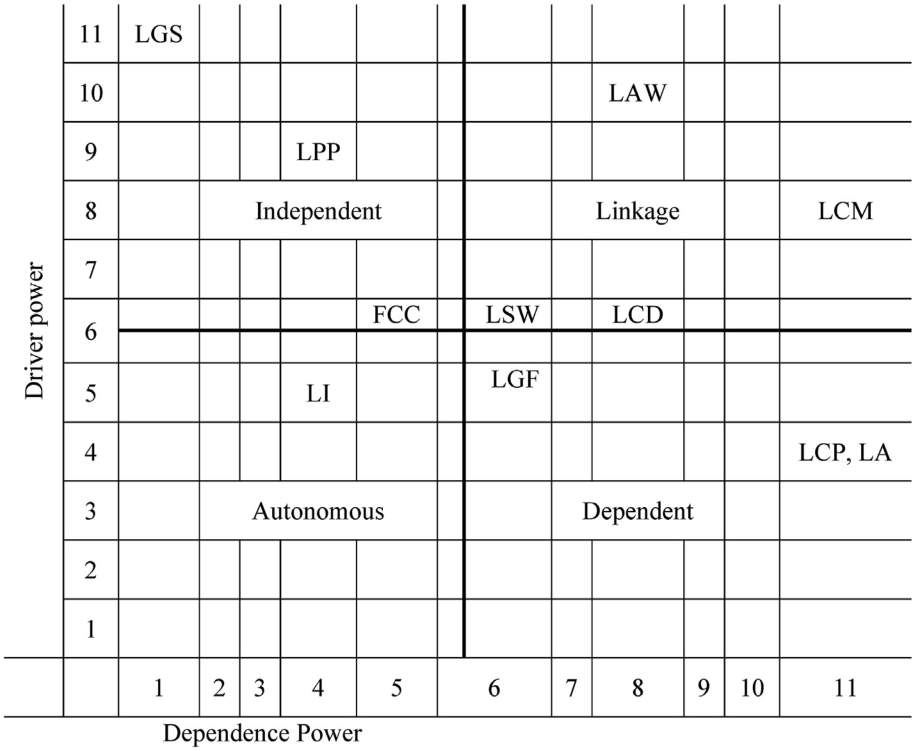

Fig. 3. Driving and dependence power diagram for Industry 4.0 and CE adoption.

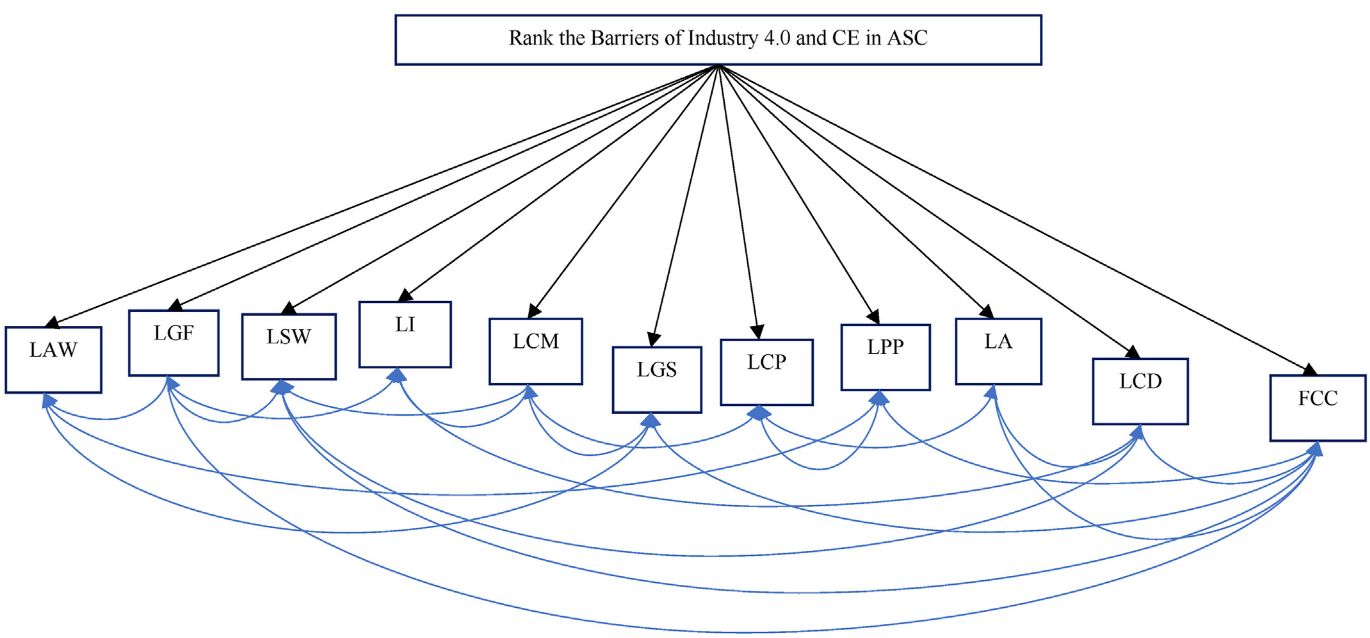

Fig. 4. ANP network.

elements in the column became identical (Table 8).

Step 12. Once the limit supermatrix was obtained, the raw column yielded the prioritized list of barriers.

5. Discussion

This research illustrated the efficiency of combined one round Delphi-ISM-ANP techniques to study the adoption barriers against I4.0 and CE in ASC. The 11 critical barriers were selected for this study after a comprehensive literature search and endorsement by the Delphi method. Then, ISM was used for determining the interrelationships between the barriers, which were then ranked using the ANP analysis.

The developed ISM model can be separated into three levels: top-level barriers, intermediate level, and bottom-level barriers. Bottom-level barriers are identified as the base of the model, and they are likely to greatly impact the other barriers. In this analysis

Table 7
The unweighted and weighted supermatrix.

	LAW	LGF	LSW	LI	LCM	LGS	LCP	LPP	LA	LCD	FCC
LAW			0.190				0.077		0.065	0.074	
LGF							0.090		0.024	0.028	
LSW							0.119		0.091	0.173	
LI					0.074		0.052		0.015		
LCM	0.1						0.014		0.037		
LGS	0.9		0.474	0.614	0.376		0.308		0.233	0.431	
LCP					0.171				0.106	0.000	
LPP		0.667	0.268	0.268	0.236		0.199		0.258	0.279	
LA					0.049		0.021			0.000	
LCD		0.333			0.094		0.091		0.108	0.015	
FCC			0.069	0.117			0.031		0.062		

Table 8
Limit supermatrix.

	LAW	LGF	LSW	LI	LCM	LGS	LCP	LPP	LA	LCD	FCC
LAW	0.061	0.061	0.061	0.000	0.061	0.000	0.061	0.000	0.061	0.061	0.000
LGF	0.015	0.015	0.015	0.000	0.015	0.000	0.015	0.000	0.015	0.015	0.000
LSW	0.047	0.047	0.047	0.000	0.047	0.000	0.047	0.000	0.047	0.047	0.000
LI	0.014	0.014	0.014	0.000	0.014	0.000	0.014	0.000	0.014	0.014	0.000
LCM	0.028	0.028	0.028	0.000	0.028	0.000	0.028	0.000	0.028	0.028	0.000
LGS	0.517	0.517	0.517	0.000	0.517	0.000	0.517	0.000	0.517	0.517	0.000
LCP	0.023	0.023	0.023	0.000	0.023	0.000	0.023	0.000	0.023	0.023	0.000
LPP	0.216	0.216	0.216	0.000	0.216	0.000	0.216	0.000	0.216	0.216	0.000
LA	0.008	0.008	0.008	0.000	0.008	0.000	0.008	0.000	0.008	0.008	0.000
LCD	0.046	0.046	0.046	0.000	0.046	0.000	0.046	0.000	0.046	0.046	0.000
FCC	0.025	0.025	0.025	0.000	0.025	0.000	0.025	0.000	0.025	0.025	0.000

Table 9
Priorities of barriers.

Barriers	Limiting value	Priorities
Lack of government support and incentives (LGS)	0.517355	Rank1
Lack of effective policy and protocol (LPP)	0.216422	Rank2
Lack of awareness (LAW)	0.060718	Rank3
Lack of skilled workforce and digital environment (LSW)	0.047309	Rank4
Lack of circular design aspect (LCD)	0.046202	Rank5
Lack of competency and motivation (LCM)	0.027657	Rank6
Fear of change of culture (FCC)	0.025114	Rank7
Lack of sustainable practices (LCP)	0.022952	Rank8
Lack of generalized framework (LGF)	0.014691	Rank9
Lack of physical and IT infrastructure (LI)	0.013873	Rank10
Lack of acceptance (LA)	0.007708	Rank11

LGS, LAW, LPP and FCC were at the bottom-level barriers, driving all the intermediate barriers LSW, LGF, LI, and LCD. Government bodies or organizations must concentrate on the bottom-level barriers to reduce the complexities in implementing I4.0 and CE for ASC. The barriers at the top level (LCM, LCP, LA) have very low influencing value as they depend on the barriers below them. Based on driving power and dependence power, all the barriers were grouped into four clusters using MICMAC analysis for further investigation.

(1) Autonomous barriers: are described as those with low dependence and driving power. The barriers falling under this category can be tackled easily and have less impact on the system. In this case, the barrier lack of infrastructure (LI) fell under this cluster.
(2) Dependent barriers: explained as a weak driver but deeply dependent on the others. Generally, these barriers appear at the top of the ISM model. In this analysis, the barriers lack of sustainable practices (LCP) and lack of acceptance (LA) came under this cluster.
(3) Linkage barriers: They have a strong driving and dependence power. Barriers falling under this cluster are considered as unstable. These unstable barriers can be influenced easily as they depend on other barriers. In this model, lack of awareness (LAW) and lack of competency and motivation (LCM) fell under this category. The Linkage Barriers have a feedback effect (Chang et al., 2013) and must be considered carefully while implementing the I4.0 and CE in ASC.
(4) Independent barriers: They have high driving power but low dependence. Such barriers demand the maximum attention of decision-makers. “Lack of government support and incentives (LGS)” and “lack of policy and protocol (LPP)” emerged as significant barriers with a strong driving force in the present study.

The result of the ISM-ANP analysis showed a similar pattern and relation among the barriers. The rank obtained in decreasing order in ANP analysis is “LGS > LPP > LAW > LSW > LCD > LCM > FCC > LCP > LGF > LI > LA”. Lack of government support and incentives (LGS) emerged as the biggest challenge for the adoption of I4.0-CE practices in ASC, followed by the lack of effective policy and protocol (LPP) and lack of awareness (LAW) in both the ISM and ANP analysis.

The government needs to financially support the ASC practitioners who implemented I4.0 and CE in their business processes, for their implementation needs high investment. Similarly, the adoption of the concept of CE becomes unprofitable for organization as the price of the virgin product is much lower than the recycled or remanufactured one. There should be the provision of some incentives from the government side to attract more organizations. Government support will be instrumental in making policies and protocols related to environmental protection for the entrepreneur in monitoring the ASC effectively. The outcome of this study is also supported by the findings of Govindan et al. (2016), who claim that weaker administration practices and lack of a specific policy lead to poor green practices. Hence, the analysis recommends developing the circular systems and business protocols that may solve legal issues and eliminate the barrier lack of policy and protocol (LPP). Lack of awareness (LAW) ranked third in the ANP analysis and was placed at level 2 in the ISM level partition. It is important to make all stakeholders of ASC properly aware regarding the benefits of modern technologies, CE, and recycled products. The importance of awareness is aligned with the findings of Brozzi et al. (2020) who highlight the societal and environmental prospects for I4.0 adoption. An increase in awareness among the stakeholders would reduce the fear of culture change (FCC). The finding is aligned with the study of Donnelly (2017) who reports the fear of change as an important factor that can be reduced by making farmers more aware of technological innovation and providing the necessary support and work. The findings of Muduli et al. (2020) also highlights the behavioral aspect of workers in order to usher in the much-needed cultural change in Indian organizations. These can be achieved by developing a digital environment and by increasing the number of training programs for the unskilled workforces. As per the report of ILO (2019), 163 industries in 44 countries are not able to adopt I4.0 and CE in their business processes due to the lack of skilled workforce (LSW). Like other developed countries, the Government of India has launched many digital programs like “BharatNet”, “Make in India”, “eNAM” etc. with the intention of creating a digital environment within the country, improve the digital infrastructure and get skilled man power (Government of India, 2019). Development of a digital environment will help in tackling the problem of lack of circular design (LCD), lack of infrastructure (LI) and the lack of generic framework (LGF). It was estimated that over 7 to 8 million jobs will be created by 2030 in the field of CE and green agriculture, once the developing countries undergo significant skill change. The development of global standards, integrated platforms and protocols for the adoption of Industry 4.0-CE may motivate the ASC practitioners to accept and enable sustainable practices in ASC.

5.1. Managerial implications and recommendations for decision-makers

The present research work was undertaken to help the practitioners and stakeholders of the agriculture supply chain for timely planning of strategy to eliminate the identified adoption barriers. Based on the three levels of the developed ISM model, the ASC practitioners can plan short, middle, and long-term strategies for effective adoption of I4.0 and CE. In a short-term strategic plan, the agri-organizations should focus on low-level barriers, i.e., on the lack of government support and incentives (LGS), lack of effective policy & protocol (LPP), lack of awareness (LAW), and fear of culture change (FCC). Government bodies and the key stakeholders of the companies should create policies encouraging the implementation of I4.0 and CE practices. It should include the transformation of culture inside and outside the organizations for creating awareness. LAW and LPP will both go hand-in-hand. LPP only finds meaning if it is known and adhered to by employees and stakeholders. Such policies lack efficiency because users do not know of them. In order to assess individual awareness organizations, need to perform surveys. Stakeholders must be given the go-ahead to share that view and be encouraged to cooperate. The government and organization should also include rewards and compensations for organizations to adopt these policies in their process. Organizations need to pressure the government to ensure financial support and incentives to build more eco-friendly products and uphold sustainable practices. It is also recommended for an organization to investigate the behavioral aspect of workers that may influence the operation due to fear of cultural change. Top management should include the lack of generalized framework (LGF), lack of physical and IT infrastructure (LI), lack of skilled workforce and digital environment (LSW), and lack of circular design aspect (LCD) in planning the intermediate strategy. Public and private companies are recommended to conduct awareness programs to train the workforce and their clients for further boosting the efficiency of the implementation process of I4.0 and CE. These programs will strengthen the relations between employers and customers and inspire both to develop a sustainable system. Lack of competency and motivation (LCM), lack of sustainable practices (LCP), and lack of acceptance (LA) can be part of the long-term strategy for ASC practitioners. Although these barriers appeared in the last of ANP rankings, they are important in the long term; also, these will take time to reduce their impact on the adoption process. This study’s recommendations and implications are also in line with the recent study of Yadav et al. (2020a) and Shen et al. (2016). The development of these strategies effectively can usher in adopting I4.0 and CE in the agriculture supply chain, which would enable the subsequent socio-economic and environmental benefits.

5.2. A unique contribution of the study

The study attempted to address the adoption of barriers against I4.0 and CE for ASC. The research helped identify different barriers and their sub-components restricting the effective implementation of integrated I4.0 and CE practices in ASC. The analysis provided recommendations for ASC professionals, service providers, and policymakers in governing bodies to plan an effective strategy for the stakeholders without losing the market during the transformation process. Barriers were finalized based on the judgment of ASC experts who were drawn from the companies that were either the starting points of the transition or were willing to transform their business operations. Further, the research employed the integrated MCDM techniques ISM and ANP to assess the interrelationships between the barriers and ascertain the importance of one barrier over others. The use of the integrated technique is supported by the recent study by Bai et al. (2020), which indicates that such studies help get a border view of the relationship between I4.0 and sustainability. Hence, the research methodology used in this study is unique and overcomes the limitation of other methods.

6. Conclusions and limitations

In the last few years, consumers have become more concerned about the environmental and sustainability issues that are pushing the agriculture supply chain players to adopt the new technologies and circular economy practices. To reach the goal of sustainability there are innovations allied to Industry 4.0 and the circular economy concept, but the replacement and transformation of conventional activities is still a major concern. This study was carried out to find the barriers concerning the adoption problem. In this study, the authors identified 11 critical barriers through literature review and the Delphi technique, structuring them in an order using the ISM technique. Based on the dependence and driving power, the identified barriers were divided into four clusters. It was found that lack of government support, lack of policy & protocol and lack of awareness had strong impacts, which could influence the adoption of Industry 4.0 and circular economy. Lack of competency and motivation, lack of sustainable practices and lack of acceptance displayed strong dependencies. Further, the dependent and independent relation of ISM was used for building the ANP network. The rank obtained in ANP analysis showed a similar trend as ISM. The three barriers with the highest driving power ranked first, second and third. These findings of this study provide valuable insights for policymakers and practitioners for developing strategies to ensure the popularity of I4.0 and CE.

Two main limitations burden the present investigation. First, the generalization of the findings of this research is limited to the agriculture sectors. For getting the barriers from other sectors, the challenges need to be redefined and adjusted. Second, both ISM and ANP analysis are based on the experts' opinions, which may differ from their expertise. The obtained model is partially biased. Every decision-making depends on the experience, interests, and some prejudice of decision-makers; hence, decision-makers' judgment is likely to vary from one another. All the selected experts were from India; therefore, the result is appropriate for Indian organizations and may be valid for other developing countries. This research work can be extended to remove the biasness with a more extensive set of data using statistical analysis and sensitivity analysis. Further, the current work can also be extended to find the cause-and-effect relationship between these barriers with a dynamic system approach.

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 A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2021.126023.

References

Ahmad, S., Wong, K.Y., 2019. Development of weighted triple-bottom-line sustainability indicators for the Malaysian food manufacturing industry using the Delphi method. J. Clean. Prod. 229, 1167–1182.
Alcayaga, A., Wiener, M., Hansen, E.G., 2019. Towards a framework of smart-circular systems : an integrative literature review. J. Clean. Prod. 221, 622–634.
Bai, C., Dallasega, P., Orzes, G., Sarkis, J., 2020. Industry 4.0 technologies assessment: a sustainability perspective. Int. J. Prod. Econ. 229, 107776.
Banerjee, A., 2019. Blockchain with IoT: applications and use cases for a new paradigm of supply chain driving efficiency and cost. In: Advances in Computers, vol. 115. Elsevier, pp. 259–292.
Belaud, J., Prioux, N., Vialle, C., Sablayrolles, C., 2019. Big data for agri-food 4 . 0 : application to sustainability management for by-products supply chain. Comput. Ind. 111, 41–50.
Brozzi, R., Forti, D., Rauch, E., Matt, D.T., 2020. The advantages of industry 4 . 0 applications for Sustainability : results from a sample of manufacturing companies. Sustainability 12 (3647).
Casado-Vara, R., Prieto, J., La Prieta, F. De, Corchado, J.M., 2018. How blockchain improves the supply chain: case study alimentary supply chain. Procedia Comput. Sci. 134, 393–398.
Chandrasekaran, N., Raghuram, G., 2014. Agribusiness Supply Chain Management. CRC Press.
Chang, A., Hu, K., Hong, Y., 2013. An ISM-ANP approach to identifying key agile factors in launching a new product into mass production. Int. J. Prod. Res. 51 (2), 582–597.
Chauhan, A., Kaur, H., Yadav, S., Jakhar, S.K., 2019. A hybrid model for investigating and selecting a sustainable supply chain for agri-produce in India. Ann. Oper. Res. 290 (1), 621–642.
Chen, Z., Ming, X., Zhang, X., Yin, D., Sun, Z., 2019. A rough-fuzzy DEMATEL-ANP method for evaluating sustainable value requirement of product service system. J. Clean. Prod. 228, 485–508.
De Corato, U., 2020. Agricultural waste recycling in horticultural intensive farming systems by on-farm composting and compost-based tea application improves soil quality and plant health: a review under the perspective of a circular economy. Sci. Total Environ. 738, 139840.
de Jesus, A., Antunes, P., Santos, R., Mendonça, S., 2019. Eco-innovation pathways to a circular economy: envisioning priorities through a Delphi approach. J. Clean. Prod. 228, 1494–1513.
Dev, Navin K., Shankar, Ravi, Hasan, Fahham, 2020. Industry 4 . 0 and circular economy : operational excellence for sustainable reverse supply chain performance. Resour. Conserv. Recycl. 153, 104583.
Donnelly, M., 2017. A culture change is needed to allow farmers farm without fear. Retrieved from. https://www.independent.ie/business/farming/agri-business/eu/a-culture-change-is-needed-to-allow-farmers-farm-without-fear-36367953.html.
FAO, 2019. A major step forward in reducing food loss and waste is critical to achieve the SDGs. Retrieved June 23, 2020, from. http://www.fao.org/news/story/en/item/1238015/icode/.
FAO, 2020. Circular economy hailed as a driver for reducing food loss and waste. Retrieved. http://www.fao.org/russian-federation/news/detail-events/en/c/1258864/. (Accessed 23 June 2020).
Fu, S., Zhan, Y., Tan, K.H., 2017. Managing social responsibility in Chinese agriculture supply chains through the "a company + farmers" model. Eur. Bus. Rev. 29 (3), 344–359.
Gardas, B.B., Raut, R.D., Narkhede, B., 2018. Modelling the challenges to sustainability in the textile and apparel (T&A) sector: a Delphi-DEMATEL approach. Sustain. Prod. Consum. 15, 96–108.
Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – a new sustainability paradigm? J. Clean. Prod. 143, 757–768.
Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32.
Ghobakhloo, M., 2020. Industry 4.0, digitization, and opportunities for sustainability. J. Clean. Prod. 252, 119869.
Government of India, 2019. India's Trillion-Dollar Digital Opportunity.
Govindan, K., Muduli, K., Devika, K., Barve, A., 2016. Investigation of the influential strength of factors on adoption of green supply chain management practices: an Indian mining scenario. Resour. Conserv. Recycl. 107, 185–194.
Green, A., Price, I., 2000. Whither FM? A Delphi study of the profession and the industry. Facilities 18 (7), 281–293.
Handayati, Y., Simatupang, T.M., Perdana, T., 2015. Agri-food supply chain coordination: the state-of-the-art and recent developments. Logistics Res. 8 (1), 1–15.
Hofmann, E., Rüsch, M., 2017. Industry 4.0 and the current status as well as future prospects on logistics. Comput. Ind. 89, 23–34.
ILO, 2019. Skills for a greener future. Retrieved from. https://www.ilo.org/wcmsp5/groups/public/—ed_emp/—ifp_skills/documents/publication/wcms_709121.pdf.
Joshi, S., Singh, R.K., Sharma, M., 2020. Sustainable agri-food supply chain Practices : few empirical evidences from a developing economy. Global Bus. Rev. 1–24.
Kamble, S.S., Gunasekaran, A., Gawankar, S.A., 2020. Achieving sustainable performance in a data-driven agriculture supply chain : a review for research and applications. Int. J. Prod. Econ. 219.
Kaur, H., 2019. Modelling internet of things driven sustainable food security system. Benchmark. https://doi.org/10.1108/BIJ-12-2018-0431.
Kirchherr, J., Piscicelli, L., Bour, R., Huibrechtse-truijens, A., Hekkert, M., Kostense-smit, E., Muller, J., 2018. Barriers to the circular Economy : evidence from the European union (EU). Ecol. Econ. 150, 264–272.
Klerkx, L., Rose, D., 2020. Dealing with the game-changing technologies of Agriculture 4.0: how do we manage diversity and responsibility in food system transition pathways? Global Food Secur. 24, 100347.
Kumar, S., Kumar, Y., Patil, P.P., Yadav, G., 2019. Logistics and distribution challenges to managing operations for corporate sustainability : study on leading Indian diary organizations. J. Clean. Prod. 238, 117620.
Lahane, S., Kant, R., Shankar, R., 2020. Circular supply chain management: a state-of-art review and future opportunities. J. Clean. Prod., 120859
Lasi, H., Fettke, P., Kemper, H.G., Feld, T., Hoffmann, M., 2014. Industry 4.0. Business Inform. Syst. Eng. 6 (4), 239–242.
Lezoche, M., Hernandez, J.E., Eva, M., Diaz, A., Panetto, H., Kacprzyk, J., 2020. Agrifood 4 . 0 : a survey of the supply chains and technologies for the future agriculture. Comput. Ind. 117.
Liao, Y., Deschamps, F., Loures, E. de F.R., Ramos, L.F.P., 2017. Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. Int. J. Prod. Res. 55 (12), 3609–3629.
Liboni, L.B., Liboni, L.H.B., Cezarino, L.O., 2018. Electric utility 4 . 0 : trends and challenges towards process safety and environmental protection. Process Saf. Environ. Protect. 117, 593–605.
Linstone, H., Turoff, M., 1975. The Delphi Method: Techniques and Applications (1st Ed. Bo). MA: AddisonWesley Publishing Company.
Li, Y., Diabat, A., Lu, C.C., 2020. Leagile supplier selection in Chinese textile industries: a DEMATEL approach. Ann. Oper. Res. 287 (1), 303–322.

Long, T.B., Blok, V., Coninx, I., 2016. Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from The Netherlands, France, Switzerland and Italy. J. Clean. Prod. 112, 9–21.
Long, T.B., Blok, V., Coninx, I., 2019. The diffusion of climate-smart agricultural innovations : systems level factors that inhibit sustainable entrepreneurial action. J. Clean. Prod. 232, 993–1004.
Lopes de Sousa Jabbour, A.B., Jabbour, C.J.C., Godinho Filho, M., Roubaud, D., 2018. Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Ann. Oper. Res. 270 (1–2), 273–286.
Luthra, S., Mangla, S.K., 2018. Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. Process Saf. Environ. Protect. 117, 168–179.
Luttenberger, L.R., 2020. Waste management challenges in transition to circular economy – case of Croatia. J. Clean. Prod. 256, 120495.
Luz, G., Mac, A., Vergara, C., Garza-reyes, J.A., Federal, U., Catarina, D.S., 2020. Organizational learning paths based upon industry 4 . 0 adoption : an empirical study with Brazilian manufacturers. Int. J. Prod. Econ. 219, 284–294.
Mangla, S.K., Luthra, S., Jakhar, S., Gandhi, S., Muduli, K., Kumar, A., 2020. A step to clean energy-Sustainability in energy system management in an emerging economy context. J. Clean. Prod. 242, 118462.
Muduli, K.K., Luthra, S., Kumar Mangla, S., Jabbour, C.J.C., Aich, S., de Guimarães, J.C.F., 2020. Environmental management and the "soft side" of organisations: discovering the most relevant behavioural factors in green supply chains. Bus. Strat. Environ. 29 (4), 1647–1665.
Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., Barbaray, R., 2017. The industrial management of SMEs in the era of Industry 4.0. Int. J. Prod. Res. 7543 (September), 1–19.
Nascimento, D.L.M., Alencastro, V., Quelhas, O.L.G., Caiado, R.G.G., Garza-Reyes, J.A., Lona, L.R., Tortorella, G., 2019. Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: a business model proposal. J. Manuf. Technol. Manag. 30 (3), 607–627.
Oesterreich, T.D., Teuteberg, F., 2016. Understanding the implications of digitisation and automation in the context of Industry 4.0: a triangulation approach and elements of a research agenda for the construction industry. Comput. Ind. 83, 121–139.
Pham, Trang Thi, Kuo, Tsai, Chi, Tseng, Ming Lang, Tan, Raymond R., Tan, Kimhua, Ika, Denny Satria, Lin, Chiuhsiang Joe, 2019. Industry 4.0 to accelerate the circular economy: a case study of electric scooter sharing. Sustainability 11 (23), 1–16.
Rajput, S., Singh, S.P., 2019. Industry 4 . 0 – challenges to implement circular economy. Benchmark Int. J. https://doi.org/10.1108/BIJ-12-2018-0430.
Ranieri, L., Urbinati, A., Facchini, F., Ole, J., 2020. A maturity model for logistics 4 . 0 : an empirical analysis and a roadmap for future research. Sustainability 12 (86).
Raut, R.D., Gardas, B.B., Narwane, V.S., Narkhede, B.E., 2019a. Improvement in the food losses in fruits and vegetable supply chain - a perspective of cold third-party logistics approach. Operations Res. Perspect. 6, 100117.
Raut, R.D., Luthra, S., Narkhede, B.E., Mangla, S.K., Gardas, B.B., Priyadarshinee, P., 2019b. Examining the performance oriented indicators for implementing green management practices in the Indian agro sector. J. Clean. Prod. 215, 926–943. https://doi.org/10.1016/j.jclepro.2019.01.139.
Roßmann, B., Canzaniello, A., Gracht, H. Von Der, Hartmann, E., 2018. The future and social impact of big data analytics in supply chain Management : results from a delphi study. Technol. Forecast. Soc. Change 130, 135–149.
Saaty, L.T., Vargas, G.L., 2013. Decision Making with Analytic Network Process (Second Edi). Springer.
Sehnem, S., Ndubisi, N.O., Preschlak, D., Juarez, R., Junior, S.S., Sehnem, S., Juarez, R., 2019. The Management of Operations Circular economy in the wine chain production : maturity , challenges , and lessons from an emerging economy perspective. Prod. Plann. Contr. 1–21.
Sharma, Y.K., Patil, P.P., Liu, S., 2019. When challenges impede the process for circular economy-driven sustainability practices in food supply chain. Manag. Decis. 57 (4), 995–1017.
Shen, L., Song, X., Wu, Y., Liao, S., Zhang, X., 2016. Interpretive Structural Modeling based factor analysis on the implementation of Emission Trading System in the Chinese building sector. J. Clean. Prod. 127, 214–227.
Tersine, R.J., Riggs, W.E., 1976. The delphi technique: a long-range planning tool. Bus. Horiz. 19 (2), 51–56.
Tortorella, G.L., Fettermann, D., 2017. Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. Int. J. Prod. Res. 56 (8), 2975–2987.
Tseng, M.L., Chiu, A.S.F., Chien, C.F., Tan, R.R., 2019. Pathways and barriers to circularity in food systems. Resour. Conserv. Recycl. 143 (December 2018), 236–237.
Tseng, M.L., Tan, R.R., Chiu, A.S.F., Chien, C.F., Kuo, T.C., 2018. Circular economy meets industry 4.0: can big data drive industrial symbiosis? Resour. Conserv. Recycl. 131 (December 2017), 146–147.
Warfield, J.N., 1974. Developing subsystem matrices in structural modeling. IEEE Trans. Syst. Man and Cyber. 4 (1), 51–81.
Xu, L. Da, Xu, E.L., Li, L., 2018. Industry 4.0: state of the art and future trends. Int. J. Prod. Res. 56 (8), 2941–2962.
Yadav, G., Luthra, S., Jakhar, S., Mangla, S.K., Rai, D.P., 2020a. A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: an automotive case. J. Clean. Prod., 120112
Yadav, S., Garg, D., Luthra, S., 2020b. Analysing challenges for internet of things adoption in agriculture supply chain management. Int. J. Ind. Syst. Eng. 36 (1), 73–97.
Yadav, V.S., Singh, A.R., Raut, R.D., Govindarajan, U.H., 2020c. Blockchain technology adoption barriers in the Indian agricultural supply chain: an integrated approach. Resour. Conserv. Recycl. 161, 104877.
Yazdani, M., Gonzalez, E.D.R.S., Chatterjee, P., 2019. A multi-criteria decision-making framework for agriculture supply chain risk management under a circular economy context. Manag. Decis. https://doi.org/10.1108/MD-10-2018-1088.
Yen, T., Min, H., Tae, G., 2017. The asian journal of shipping and logistics application of fuzzy delphi TOPSIS to locate logistics centers in Vietnam : the logisticians' perspective. Asian J. Shipping Log. 33 (4), 211–219.
Yi, P., Li, W., Zhang, D., 2021. Sustainability assessment and key factors identification of first-tier cities in China. J. Clean. Prod. 281, 125369.