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Challenges of Applying Circular Economy in Agricultural Sustainable Development: A Case Study of Kurdistan Province, Iran

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Abstract

Current production and distribution models in agriculture primarily operate based on the 'linear economy' approach. This means that after the exploitation of natural resources and the production of the final product, a significant portion of these resources and products, now contaminated or turned into waste, exit the economic cycle. The circular economy approach in agriculture seeks to reuse waste products and depleted inputs, thereby reducing the intensity of resource exploitation and taking a step towards sustainable agriculture. However, applying circular economy concepts in agriculture across different regions, especially in developing countries like Iran, can encounter various obstacles and challenges. The present study aims to identify and analyze these obstacles and challenges in the agriculture sector of Kurdistan Province, one of Iran's key agricultural regions. For this purpose, after reviewing the literature and gathering expert opinions from the province's agrarian elites, 16 challenging factors were identified as potential barriers to expanding the circular economy in Kurdistan Province. These were examined and analyzed using the Interpretive Structural Modeling (ISM) approach. The required data were collected via a questionnaire in the spring of 2024. The research findings indicate that among the 16 factors analyzed, the key variables are the second, first, and third factors—namely, the illiteracy and low literacy rates among farmers, traditional and subsistence farming, and the small size and fragmentation of agricultural lands in Kurdistan Province. According to the experts and specialists interviewed, addressing these variables can significantly influence others, reducing the barriers and challenges facing the circular agricultural economy and the sustainable development of agriculture in Kurdistan Province.

Keywords
Circular economy; interpretive structural modeling; sustainable agriculture

1. Introduction

The Circular Economy (CE) is an economic model and perspective aimed at minimizing waste and making the most sustainable use of resources possible. This regenerative approach to resources and the environment contrasts with the traditional or linear capitalist economy, where the production and consumption process typically follows the pattern of "extracting raw materials, producing, consuming, and discarding the remaining waste to facilitate further consumption." In the circular economy perspective, the consumption of inputs and resources and the output of waste and energy loss is minimized by closing or narrowing material and energy loops through design, maintenance, repair, reuse, remanufacturing, and recycling [1, 2, 3]. With circular approach to resource utilization, long-term sustainability goals and environmental protection can be achieved. Advocates of this view argue that the sustainability achieved by the circular economy model does not imply a reduction in the level of consumption or quality of life for consumers, and it can be realized without significant additional costs for producers (or a reduction in their income) [4, 5]. CE strategies seek to keep materials in the eco-sphere and the techno-sphere for as long as possible rather than “discarding” them. This should help reduce resource use and energy demand within a product's life cycle [6].

The core philosophy of the Circular Economy is the optimal use of limited resources, waste reduction, and the reuse of waste in production processes or the creation of by-products. Unlike the linear economy, where the primary goal of enterprises is profit maximization, the Circular Economy also emphasizes waste management and minimizing the use of inputs. The Circular Economy can increase added value and profit margins, save costs, enhance competitiveness, reduce environmental pollution, and create new job opportunities. Some advanced countries like Germany, Japan, the European Union, and China have implemented national and sectoral Circular Economy initiatives through legal measures and establishing governmental institutions over the past two decades, reaping its benefits [7].

Global agricultural production and service delivery methods predominantly operate according to a "linear economy" model. As previously mentioned, in this model, after extracting natural resources and converting them into final goods, they are discarded as waste at the end of their useful life. This waste is considered a loss and is not reused. Additionally, the linear economy fails to account for the physical depletion and loss of value of natural resources and environmental pollution and degradation. As a result of this irresponsible behavior, Tolkien writes in The Lord of the Rings: "In some places, rivers, lakes, and springs have vanished. Roses have withered in fire, smoke, and dust, and idyllic villages have become the dwelling place of ghosts." It is easy to predict that the consequences of such actions include deforestation, droughts, water, air, and soil pollution, depletion of natural resources, floods and tsunamis, pollutants, climate change, and numerous other issues. Humanity must find an alternative to the linear economy. The circular economy is emerging as a substitute for the linear economy, guiding human society away from consumerism toward more efficient use of existing natural resources and energy. The circular economy seeks to prevent waste and resource depletion as much as possible by promoting sharing, renting, reusing, repairing, refurbishing, and recycling materials and products, thereby extending the life cycle of products. In other words, the circular economy aims to minimize waste to the greatest extent possible. When a product ends its life, its materials are kept in the economy for as long as possible. These materials can be used repeatedly, creating more value [8].

The significance of adopting a circular economy approach, particularly in the agricultural and natural resources sectors, and the need to focus on circular agricultural economics in the world, Iran, and the Kurdistan Province stems from the growing population and the corresponding increase in demand for food. However, the supply of agricultural inputs and natural resources, especially water, is limited and becoming increasingly scarce. For instance, rural water availability is not only non-expandable but is also facing a significant decline due to climate change and the overexploitation of groundwater reserves. The traditional linear agricultural approach contributes to environmental pollution, including chemical waste in soil and water resources, besides CO_2 emissions in the atmosphere. Accordingly, shifting from a linear economy to a circular economy in agriculture is crucial to achieving agricultural sustainability [9, 10]. The circular economy is proposed to mitigate the ecological challenges by maintaining resources within the economic cycle through material recycling and adopting renewable energy sources [11]. In recent years, the circular economy concept has become a popular strategy for reducing food and resource waste. Farmers and food producers can achieve circular economy sustainable development goals by minimizing food and resource waste, contributing to hunger and poverty alleviation [12]. Agriculture is the most water-intensive economic activity in the world [13]. Accordingly, adopting circular economy strategies could help wastewater recycling and management. New methods have been developed for circular agriculture. Agrivoltaics – or Agri-PV – is the synergy of agriculture and photovoltaic technology. It's the risk-free key to maximizing the potential of your land without interfering with your livestock or impacting your crop cultivation. Agrivoltaics combines photovoltaic and agricultural systems to create a synergistic arrangement where land can be utilized more efficiently. The development of CE is a fundamental way to achieve sustainable agricultural development [14, 15].

Homrich et al. [16], by studying a sample composed of 327 articles extracted from the Web of Science and Scopus database, showed a lack of consensus on terminologies and definitions. Thus, based on semantic analysis, a definition is proposed. In addition, the literature shows two main clusters, with different backgrounds, of other leading research groups in distinctive geographic regions.

Marami et al. [17] studied the impact of geopolitical conditions on the environmental benefits of circular bioeconomy, explicitly focusing on converting organic waste into lactic acid and bioenergy. They compared biorefinery platforms in Denmark and Iran, representing developed and developing countries.

Despite all the advantages and benefits of circular economy, transitioning from a traditional agricultural economy to a circular one, particularly in developing countries, is challenging. The agricultural system in such regions is predominantly traditional and peasant-based, with most production carried out by illiterate or semi-literate villagers on small, scattered, semi-subsistence farms using outdated technologies. Furthermore, the lack of adequate transportation and processing infrastructure and extensive government intervention in suppressing agricultural product prices adds to the difficulties. This study aims to identify and analyze these barriers and challenges for agriculture in Kurdistan Province, Iran. In Iran, a developing country with agriculture as a traditional sector of the economy, the circular economy concept is a relatively new paradigm. As a result, few studies have been conducted on this subject.

Abedi [18] examined the barriers to adopting the Circular Economy and the Fourth Industrial Revolution in the agricultural supply chain using the ISM-DEMATEL combined method, highlighting their crucial role. The study identifies the primary obstacles to expanding the circular economy within Iran's agricultural supply chain as a lack of governmental support and incentives, an absence of sustainable production methods, and insufficient competency and motivation among producers active in the supply chain.

Mehrabi et al. [19] emphasize that globalization has intensified global competition, prompting organizations and companies to continuously seek ways to minimize surplus waste, enhance reuse, maintain environmental balance, and improve their market position and image. In industrial and modern agriculture, the Fourth Industrial Revolution offers a significant opportunity to address variability and uncertainties in the agricultural food production chain. Their findings indicate that the absence of appropriate sustainable farming practices is the most critical barrier to achieving a sustainable supply chain. Furthermore, the study reveals inadequate planning and policy-making, along with a lack of awareness among decision-makers regarding Industry 4.0, constitute the second and third most significant barriers to sustainable supply chain operations of agricultural products in Khuzestan Province.

Kiani et al. [20] conducted a study to identify and analyze the relationships between the barriers to implementing the circular economy in the supply chain of the Ardakan Glass Factory in Yazd. The study yielded results in both qualitative and quantitative sections. The qualitative section identified and categorized barriers using a meta-synthesis approach. In contrast, the fuzzy DEMATEL method was employed in the quantitative section to model the relationships between these barriers and prioritize them. The qualitative findings revealed 24 obstacles across five dimensions, and the quantitative findings indicated that economic, infrastructural, and legal technical obstacles are among the most influential (causal) dimensions.

As the literature review indicates, up to the time of writing this article, no domestic study in Kurdistan Province, Iran, has expressly and directly examined or analyzed the barriers and challenges to expanding the circular economy in the agricultural sector. Kurdistan Province in Iran is highly suitable for agriculture and the pasture industry, making it an ideal candidate for implementing a circular economy. The province covers 2.9 million hectares, including 1 million hectares of farmland and 1.7 million hectares of forests and rangelands. Additionally, Iranian Kurdistan has extensive surface and underground water resources supporting the region's economic, agricultural, and industrial sectors for decades. However, the overexploitation of these resources has led to significant environmental degradation and unsustainability [21]. Sustainable resource management through circular economy principles could mitigate these challenges by promoting waste reduction, resource regeneration, and long-term environmental resilience. This study pioneers this area by introducing circular economy concepts and applying the Interpretive Structural Modeling (ISM) method. Furthermore, given that the conditions in Iran's Kurdistan Province can reflect those of many traditional agricultural regions worldwide, this study could be both inspiring and valuable on a global scale in identifying and analyzing the barriers to expanding the circular economy and developing sustainable agriculture.

2. Methods and Data

2.1 Model Description

In the present study, while introducing and highlighting the significance and role of the circular economy in the agricultural sector and agricultural economics, the perspectives of agricultural experts and specialists regarding the existing limitations in implementing and expanding the circular economy model in Kurdistan Province were gathered through the design and completion of a researcher-developed questionnaire. Subsequently, the barriers were examined and prioritized using the Interpretive Structural Modeling (ISM) method. The ISM method is a structured interpretive approach that analyzes the relationships between criteria and indicators by breaking them down into several levels [22]. ISM can determine the levels of interconnections between interdependent indicators individually or in groups. In other words, ISM can be used to analyze the relationships between various features defined for a given problem (Figure 1).

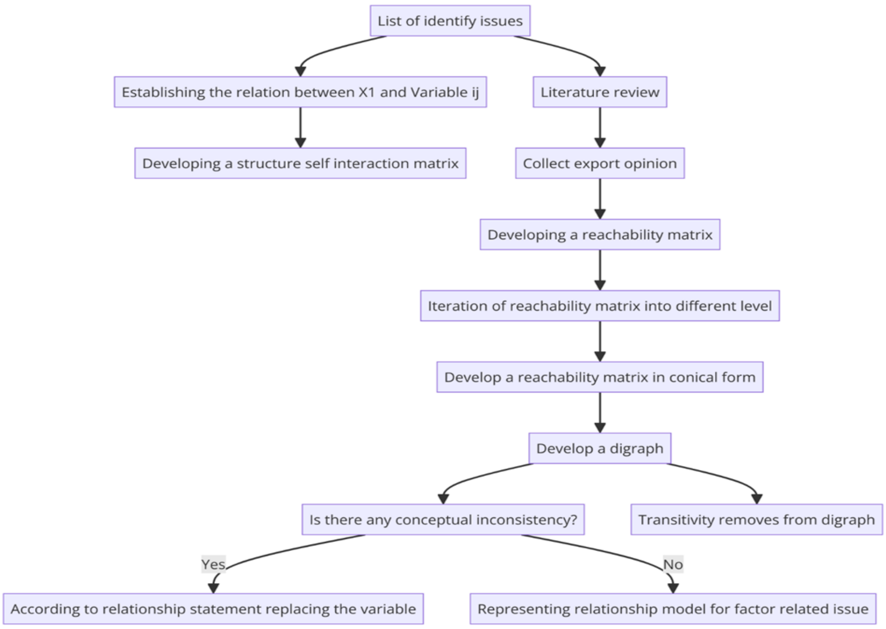

Figure 1 Flow chart of Interpretive Structural Modeling (ISM).

This method first organizes the factors influencing the subject under study into different levels and then clarifies the relationships between these factors across distinct levels [23, 24]. Designing an ISM model for interrelated variables is a method used to assess the impact of each variable on others. This approach is interpretive because it relies on group judgments to determine whether a relationship exists between these elements. Simultaneously, it is structural because the relationships are based on an overarching structure derived from a complex set of variables. ISM can be applied in management and systems behavior analysis, including assessing barriers to the circular economy. The ISM technique begins by identifying variables relevant to the topic under discussion. In this study, the variables for model design were factors identified by researchers and refined and validated by experts. Once the variables are identified, they are entered into the Structural Self-Interaction Matrix (SSIM). This matrix, which corresponds to the dimensions of the variables, lists the variables in the first row and column, respectively. The pairwise relationships between the variables are then indicated using symbols. In this model, the relationships between the dimensions and indicators are analyzed using the "leads to" conceptual relationship after identifying the study's dimensions and indicators. The Structural Self-Interaction Matrix comprises the study's dimensions and indicators, and their comparison is conducted using four types of conceptual relationships. Experts and specialists in the field complete this matrix. The group decision-making rule establishes consensus on the relationship between each pair of elements, such as A and B. A common approach is to use expert voting for collective agreement. Suppose individuals cast their votes on whether element A dominates element B (or vice versa or is ineffective). In that case, the relationship between A and B, which receives more than half the votes, is selected. The logic of ISM operates based on nonparametric methods and is grounded in the mode of frequency distributions.

In this study, the Structural Self-Interaction Matrix was developed after identifying the most critical potential barriers to the expansion of the circular economy using the standard ISM symbols (V, A, X, O). In the context of Interpretive Structural Modeling (ISM), the Structural Self-Interaction Matrix (SSIM) is a tool used to identify and describe the relationships between different elements within a system. The SSIM uses specific symbols to denote the type of interaction between pairs of elements. Here's what the symbols V, A, X, and O represent:

V: (Element i leads to Element j), indicating that Element i directly influences Element j. In other words, i causes j.

A: (Element j leads to Element i), indicating that Element j directly influences Element i. In other words, j causes i.

X: (Element i and Element j mutually influence each other), signifies a bi-directional relationship where Element i and Element j influence each other simultaneously.

O: (No Direct Relationship) indicates no direct interaction between Element i and Element j.

Following this, the initial reachability matrix was obtained by converting the Structural Self-Interaction Matrix into a binary matrix of zeros and ones. In this matrix, the number one replaces the symbols X and V, while the symbols A and O are replaced by zero. The resulting matrix is known as the initial reachability matrix. The diagonal entries are set to one. Once the initial reachability matrix is established, its internal consistency must be ensured. For example, if variable A leads to variable B, and variable B leads to variable C, then variable A should also lead to variable C.

If this condition is not met in the initial reachability matrix, the matrix must be revised, and any omitted relationships should be added, in the final reachability matrix. Various methods have been proposed to ensure matrix consistency. Secondary relationships should be checked to verify, meaning if A leads to B and B leads to C, then A should also lead to C. If this does not happen in practice, the table must be corrected, and secondary relationships can be indicated with an asterisk (*1) in the corresponding table.

After the final reachability matrix is constructed, the relationships and levels of the criteria must be determined by extracting the set of outputs and inputs for each criterion from the reachability matrix. The output set includes the criterion itself and those it influences, while the input set includes the criterion itself and those that influence it. The two-way relationships between criteria are then identified. The first row, where the intersection of the two sets equals the reachability set (inputs), is recognized as the priority level. If the junction of the input and output sets is equal, the corresponding variable is placed at the highest level of the ISM hierarchy. After determining the level, the identified criterion is removed from the table, and the input and output sets are formed again to identify the next level of variables. This process continues until all variables are leveled. After the leveling is complete, the structural model diagram for the problem can be created from the final reachability matrix. If there is a relationship between variable i and variable j, it is shown with a directional arrow. The final diagram is obtained by eliminating transitive relationships and using the leveling section.

Following these steps, MICMAC analysis is conducted. The purpose of MICMAC analysis (short for Impact Matrix Cross-Reference Multiplication Applied to a Classification) is to examine and analyze the driving and dependence power of the components calculated during the formation of the final reachability matrix. It is important to note that studying the driving and dependence power of the components is part of the ISM process, and the calculations are performed using Excel software. In this analysis, variables are classified into four general categories, each with its own interpretation [25]:

Autonomous Variables: These components have weak dependence and driving power. They operate independently of the overall system and have minimal impact on other elements, with minimal connections to them.

Dependent Variables: These have weak driving power but higher dependence, meaning other components influence them more.

Linkage Variables: These have intense driving and dependence power. These variables are unstable, meaning any action taken regarding them directly impacts other components and, in turn, can feed back and affect the variable itself.

Independent Variables: These have strong driving power but weak dependence, making them key variables. Changes in these variables can significantly influence others.

After determining the driving and dependence power of the components, they can be classified into one of the four clusters mentioned above. A crucial point is to define the boundary between these categories. The boundary points are typically one unit larger than the average number of components. In other words, if there are n components, the boundary line is determined as follows:

$$\boldsymbol{B = 1 + (\frac{n}{2})} \tag{1}$$

After reviewing the literature and gathering initial feedback from interviewed experts, 16 factors were identified as potential barriers to expanding the circular economy in Kurdistan Province. These factors include:

Traditional and subsistence agriculture: This limits innovation and adopting sustainable practices, as farmers focus more on immediate survival than long-term sustainability.

Illiteracy and low literacy among farmers: Farmers may lack the knowledge and skills to implement circular economy practices, reducing their ability to adopt new, more sustainable techniques.

Small and fragmented agricultural plots: Such plots hinder economies of scale, making implementing efficient and cost-effective recycling and waste management systems difficult.

Low agricultural productivity: Limited productivity reduces the capacity to invest in circular economy technologies or systems, as farmers focus on meeting basic production needs.

Government suppression of agricultural product prices discourages investment in innovative practices, as farmers cannot increase their income by selling products.

Irrational subsidies for fertilizers and pesticides: These subsidies encourage the overuse of harmful inputs, undermining sustainable farming practices and inhibiting the transition to eco-friendly alternatives.

Lack of product storage capacity: Insufficient storage leads to higher waste and spoilage rates, preventing efficient use of resources and recycling efforts.

Improper and unscientific use of agricultural inputs: This contributes to environmental degradation, reducing the effectiveness of circular economy practices by damaging ecosystems needed for sustainable farming.

High costs of precision agricultural equipment: Expensive technology is out of reach for many farmers, limiting their ability to implement circular economy methods such as resource-efficient farming and waste reduction.

Weak transportation infrastructure: Poor infrastructure makes it challenging to collect and transport agricultural waste or recycled materials, hindering the development of circular systems.

Inadequate communication and internet infrastructure: Lack of access to information and digital tools reduces farmers' ability to learn about and adopt circular economy practices.

Lack of banking facilities: Farmers struggle to invest in the necessary technology or processes supporting circular economy initiatives without access to finance.

Shortage of agricultural research personnel: The lack of expertise limits innovation and the development of sustainable practices tailored to local conditions.

Weak linkage between research, education, and innovation with farmers: A disconnect between academia and farmers means that research advancements are not effectively applied.

Scarcity of processing and recycling workshops for product waste: Without sufficient facilities to recycle agricultural waste, valuable materials are lost, preventing the establishment of a closed-loop system.

Insufficient rural and agricultural wastewater treatment facilities: Inadequate wastewater treatment leads to pollution, reducing the availability of clean water for reuse in agriculture and inhibiting sustainable water management practices.

2.2 Data Sources

Following the identification of the most significant potential barriers to the expansion of the circular economy, a questionnaire was designed by the principles of Interpretive Structural Modeling (ISM). The questionnaire was structured as a 16×16 matrix (as shown in Table 1), with the 16 identified factors listed in both the rows and columns. Respondents were asked to determine the pairwise relationships between the factors using the standard ISM symbols (V, A, X, O) explained in the questionnaire and described in detail in the methodology section.

Table 1 Structural Self Interactive Matrix.

Challenging Factors	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**
Traditional and subsistence agriculture (A1)		A	V	V	O	O	O	O	O	X	X	V	O	O	O	O
Illiteracy and low literacy among farmers (A2)			O	V	O	O	O	V	O	O	O	O	V	V	O	O
Small and fragmented agricultural plots (A3)				V	X	O	V	V	O	O	O	O	V	V	O	O
Low agricultural productivity (A4)					X	O	O	O	O	O	O	O	V	O	O	O
Government suppression of product prices (A5)						O	O	O	O	O	O	O	V	O	O	O
Subsidies for fertilizers and pesticides (A6)							O	X	X	O	O	O	O	O	O	O
Lack of storage capacity for products (A7)								O	O	O	O	O	A	A	O	O
Improper and unscientific use of agricultural inputs (A8)									O	O	O	V	O	O	V	O
High costs of precision agricultural equipment (A9)										V	V	A	O	O	O	O
Weak transportation infrastructure (A10)											X	O	O	O	O	O
Inadequate communication and internet infrastructure (A11)												A	O	V	O	O
Lack of banking facilities (A12)													A	O	V	V
Shortage of agricultural research personnel (A13)														V	O	O
Weak linkage between research, education with farmers (A14)															O	O
Scarcity of recycling facilities for wastes (A15)																O
Insufficient agricultural wastewater treatment facilities (A16)																

Source: Research Findings.

The designed questionnaire, based on the standard ISM model and after final revision and editing, was distributed in the spring of 2024 to 30 faculty members of the College of Agriculture at the University of Kurdistan and senior experts from the Agricultural Jihad Organization, who are recognized as agricultural experts in the province. Their responses were collected using the questionnaire above, and the gathered data was compiled and analyzed using the ISM method.

3. Results

3.1 The Structural Self-Interaction Matrix

The Structural Self-Interaction Matrix, Table, was developed from the data collected. In cases where n respondents provided their judgments on whether element A dominates element B (or vice versa, or is neutral), the relationship between A and B that received more than half of the votes was selected.

3.2 Initial Reachability Matrix

After constructing the structural self-interaction matrix as described above, the initial reachability matrix (Table 2) was obtained by converting the structural self-interaction matrix into a binary (0-1) matrix, as explained in the methodology section. To derive the initial reachability matrix, the following rules are applied to each row of the structural self-interaction matrix as follow:

Suppose the entry at position (i, j) in the structural self-interaction matrix is V. In that case, the initial reachability matrix's corresponding entry (i, j) is set to 1, and the entry at position (j, i) is set to 0.

If the entry at position (i, j) in the structural self-interaction matrix is A, then the corresponding entry (i, j) in the initial reachability matrix is set to 0, and the entry at position (j, i) is set to 1.

If the entry at position (i, j) in the structural self-interaction matrix is X, then the corresponding entries (i, j) and (j, i) in the initial reachability matrix are both set to 1.

If the entry at position (i, j) in the structural self-interaction matrix is O, then the corresponding entries (i, j) and (j, i) in the initial reachability matrix are both set to 0.

If I = j, meaning the diagonal of the matrix, the entry in the initial reachability matrix is set to 1 [26].

Table 2 Initial Reachability Matrix.

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**
A1	1	0	1	1	0	0	0	0	0	1	1	1	0	0	0	0
A2	1	1	0	1	0	0	0	1	0	0	0	0	1	1	0	0
A3	0	0	1	1	1	0	1	1	0	0	0	0	1	1	0	0
A4	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
A5	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
A6	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
A7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
A8	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0
A9	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	1

A10	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
A11	1	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0
A12	0	0	0	0	0	1	0	0	1	0	1	1	0	0	1	1
A13	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
A14	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0
A15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
A16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Source: Research Findings.

3.3 The Final Reachability Matrix

The final reachability matrix (Table 3) resolves the internal inconsistencies of the initial reachability matrix by accounting for the indirect effects among factors. Specifically, if (i, j) are connected and (j, k) are also connected, then (i, k) will be connected as well. In this matrix, each variable's driving power and dependency level are also calculated. The numbers marked with an asterisk (*) indicate zero entries in the initial reachability matrix but changed to one after adjustment for consistency.

Table 3 Final Reachability Matrix.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	Driving Power
A1	1	0	1	1	1*	0	1*	1*	0	1	1	1	0	1*	0	0	10
A2	1	1	0	1	1*	0	0	1	0	0	0	1*	1	1	1*	1*	10
A3	0	0	1	1	1	0	1	1	0	0	0	1*	1	1	1*	1*	10
A4	0	0	1*	1	1	0	0	0	0	0	0	0	1	1*	0	0	5
A5	0	0	1*	1	1	0	0	0	0	0	0	1*	1	1*	0	0	6
A6	0	0	0	0	0	1	0	1	1	1*	1*	1*	0	0	1*	1*	7
A7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
A8	1*	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	4
A9	1*	0	0	0	0	1	0	0	1	0	0	1	0	0	1	1	6
A10	1	0	0	0	0	1*	0	0	0	1	1	0	0	0	0	0	4
A11	1	0	0	0	0	1	0	0	0	1	1	0	1*	1	0	0	6
A12	1*	0	0	0	0	1	0	0	1	1*	1	1	0	0	1	1	8
A13	0	0	1*	0	0	0	1	0	0	0	0	0	1	0	0	0	3
A14	1*	0	0	1*	1	1*	1	0	0	0	0	0	0	1	0	0	6
A15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
A16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence Power	8	1	5	6	6	7	5	5	2	5	5	7	6	7	7	6	

Source: Research Findings,
'*' Denotes adjusted relationsip after consistency.

3.4 Level Partitioning of Variables

In the next step, the levels of the components are determined using the final reachability matrix, as shown in Table 4.

Table 4 Level Partitioning of Factors.

Repetition	Factor	Output set	Input set	The intersection of the input and the output sets	Rank of Level
First	A7	7	1,3,7,11,13,14	7	1
	A10	1,6,10,11	1,6,9,10,11,12	1,6,10,11	1
	A13	3,13	1,2,3,4,5,11,13	3,13	1
	A14	1,4,5,11,14	1,2,3,4,5,11,13,14	1,4,5,11,14	1
	A15	15	2,3,5,6,8,12,15	15	1
	A16	16	2,3,5,6,8,12,16	16	1
	A4	3,4,5	1,2,3,4,5	3,4,5	1
	A6	6,8,9,11,12	6,8,11,12,14	6,8,9,11,12	1
Second	A8	6,8	1,2,3,4,5,6,8	6,8	2
	A9	6,9,12	6,9,12	6,9,12	2
	A11	1,6,11	1,6,9,11,12,14	1,6,11	2
Third	A12	1,12	1,2,3,5,12	1,12	3
Fourth	A3	3,4,5	1,3,4,5	3,4,5	4
	A5	3,4,5	1,2,3,4,5	3,4,5	4
Fifth	A1	1	1,2	1	5
Sixth	A2	2	2	2	6

Source: Research Findings.

After identifying the input and output sets, the intersection of these sets is obtained for each barrier to determine the levels of the components. The items in this study were categorized into six iterations or levels. The output set of an index includes the index itself and the indices it influences, identifiable by the "1"s in the corresponding row of the final reachability matrix. The input set of an index includes the index itself and the indices that influence it, identifiable by the "1"s in the corresponding column. After determining the input and output sets, their intersection is identified for each variable. Variables for which the output set and their intersection are identical are placed at the highest level of the interpretive structural modeling hierarchy. To identify the components of the next level, the highest-level components are removed from the relevant table's mathematical calculations, and the process of determining the next level's components is conducted in the same manner. This process is repeated until the components of all levels of the system are identified [27].

3.5 The Final Diagram of the Interpretive Structural Model

Finally, after determining the levels of the variables, a simplified diagram of the interpretive structural model can be created from the final reachability matrix. If there is a connection between variable i and variable j, it is represented by a directed arrow. The final diagram is obtained by removing transitive relationships and using the level determination table. Figure 2 illustrates this diagram.

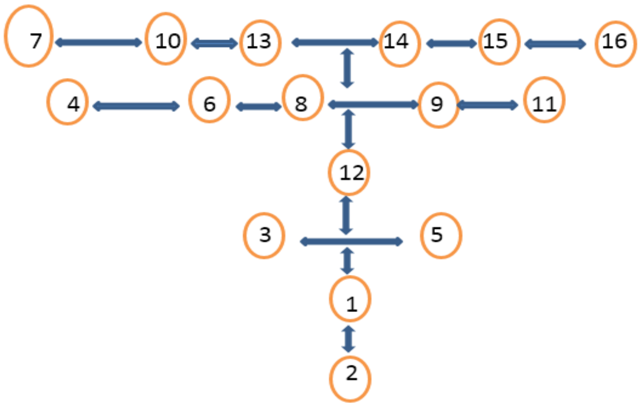

Figure 2 The final diagram of the Interpretive Structural Model (ISM).

3.6 MICMAC Analysis

After completing the above steps, Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC) analysis is conducted. In this analysis, variables are categorized into four groups based on their level of driving power on other variables and their degree of dependence power on them: autonomous variables, dependent variables, linkage variables, and independent variables.

The driving and dependence diagram for the variables in this study (Figure 3) was plotted using a boundary value of 9, which is equivalent to one unit more significant than the average number of components:

$$\boldsymbol{B = 1 + \left(\frac{16}{2}\right) = 9} \tag{2}$$

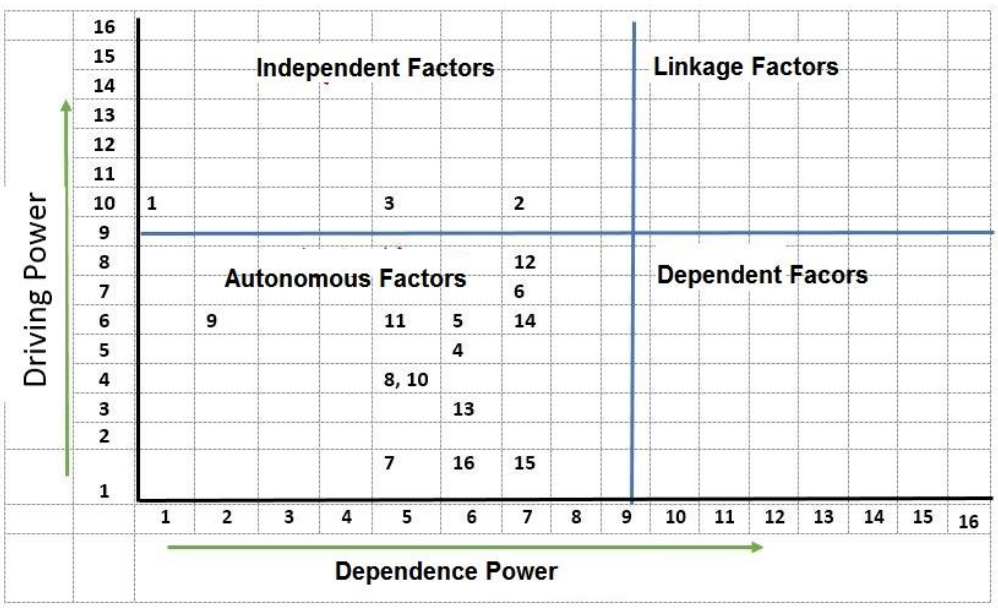

Figure 3 Driving and Dependence Power Diagram.

4. Discussion

The implementation of the Interpretive Structural Modeling (ISM) process and the ranking of factors revealed that factors 7, 10, 13, 14, 15, and 16—namely, the lack of storage capacity for products, weaknesses in transportation infrastructure, shortage of human resources in agricultural research, weak linkage between research, education, innovation, and farmers, shortage of facilities for product waste conversion and recycling, and lack of rural and agricultural wastewater treatment facilities—are the variables that ranked in first level, having the lowest impact on the expansion of the circular economy in the Kurdistan Province.

At the second level, factors 4, 6, 8, 9, and 11—specifically, low agricultural productivity, irrational subsidies for fertilizer and pesticide inputs, improper and corrupt use of agricultural inputs, high costs of precision agriculture equipment, and weaknesses in communication and internet infrastructure—were identified as having a relatively more significant impact than the first-level components.

Following these, factor 12 (shortage of banking facilities) is positioned at the third level, factors 3 (illiteracy and low literacy among farmers) and 5 (price suppression of agricultural products by the government) at the fourth level, factor 1 (traditional and subsistence farming) at the fifth level, and factor 2 (small and fragmented agricultural plots) at the sixth level, each sequentially contributing more to limiting the potential expansion of the circular economy in the studied region.

Furthermore, the analysis of variables based on their influence on other variables and their dependency on others (MICMAC analysis) and the categorization of factors revealed that 13 out of the 16 components studied in this research—namely, low agricultural productivity, government price suppression of agricultural products, irrational subsidies for fertilizer and pesticide inputs, lack of storage capacity for products, improper and corrupt use of agricultural inputs, high costs of precision agriculture equipment, weaknesses in transportation infrastructure, weaknesses in communication and internet infrastructure, shortage of banking facilities, shortage of human resources in agricultural research, weak linkage between research, education, innovation, and farmers, shortage of facilities for product waste conversion and recycling, and lack of rural and agricultural wastewater treatment facilities—are classified as “autonomous variables.” This category of components has both weak dependency and weak influence, meaning that they operate largely independently from the overall system. These components have minimal impact on other elements, and their connections are limited and insignificant.

On the other hand, three components—traditional and subsistence farming, illiteracy and low literacy among farmers, and the small and fragmented nature of agricultural plots—are classified as “independent variables.” These variables have strong influence but weak dependency, making them key variables; changes in these can significantly affect the other variables.

5. Conclusions and Recommendations

As reviewed and examined in this study, production and distribution patterns in agriculture primarily operate according to the "linear economy" model. This means that after the exploitation of natural resources and the production of final goods, a significant portion of these resources and products exit the economic cycle as waste or pollutants. Most of these wastes and depleted resources are considered losses and are not reused. The circular economy model in agriculture seeks to break away from this flawed structure by promoting the reuse of waste products and lost inputs to reduce the strain on resource exploitation and take a step toward sustainable agriculture.

Given the importance of understanding and transitioning toward a circular agricultural economy, this study was conducted in Kurdistan Province, a significant agricultural region in a developing country, Iran. For this purpose, after reviewing the literature and gathering expert opinions from agricultural specialists in the province, 16 factors were identified as potential barriers to expanding the circular economy in Kurdistan. These factors were analyzed using the Interpretive Structural Modeling (ISM) approach.

The results of the research showed that among the 16 factors examined, 2, 1, and 3 factors—namely, illiteracy and low literacy among farmers, traditional and subsistence farming, and the small and fragmented nature of agricultural plots in Kurdistan Province—are identified by experts and interviewees as key variables. Changing these can influence the other variables and reduce the obstacles and challenges facing the circular agricultural economy in Kurdistan Province.

In light of these results, it becomes evident that fostering the engagement of the younger, educated generation in agriculture through large-scale, long-term initiatives is a crucial prerequisite for achieving sustainable development and ensuring the effective implementation of the circular economy (CE) model in agricultural regions of developing countries like Iran. A critical aspect of this transformation involves shifting from traditional subsistence farming to a modern, commercial agricultural system. This shift addresses the structural and economic inefficiencies of small-scale farming. It facilitates the integration of innovative CE practices, such as waste reduction, resource optimization, and improved input-output cycles, which are essential for long-term sustainability.

The study by Dziedzic et al. [28] emphasizes a similar need for educating and informing the agricultural workforce about the principles and benefits of the CE model. Their study, which spans seven countries—Brazil, Germany, Japan, Mexico, Morocco, Portugal, and Taiwan—highlights the importance of incentivizing farmers to adopt circular practices. These incentives, ranging from policy-driven subsidies to technological support, are essential to overcoming resistance to change and ensuring that the older generation of farmers and younger, more educated individuals see value in adopting circular agricultural practices. By implementing targeted educational programs and incentives, regions such as Kurdistan could better motivate farmers and agricultural workers to engage in sustainable practices.

Furthermore, practical examples from regions like the Netherlands and Japan provide critical insights into how circular agricultural systems can be effectively applied. These countries have made significant strides in adopting circular agriculture through improving waste recycling systems, promoting precision farming, and establishing cooperative farming frameworks. Precision farming technologies, such as using sensors and data analytics to optimize water and fertilizer use, can be particularly effective in areas like Kurdistan, where resource scarcity poses a significant challenge. Additionally, the cooperative frameworks developed in these countries allow small-scale farmers to pool resources and share knowledge, thus overcoming the structural limitations imposed by fragmented landholdings.

To enhance the motivation of the younger, educated generation in Kurdistan and facilitate the transition to modern, commercial agriculture, introducing feasible applications of circular agriculture through the agricultural education and extension system is essential. Agricultural extension services play a pivotal role in disseminating knowledge and promoting the adoption of innovative farming practices. By integrating CE principles into these programs, farmers can be educated on the economic and environmental benefits of resource efficiency, waste reduction, and sustainable farming techniques.

Wastewater recovery is a critical factor for sustainable agricultural systems in the circular economy in the rural sector in Kurdistan, where water scarcity and inefficient resource management are pressing concerns. Establishing an extension program focused on wastewater recycling in Kurdistan Province could be an impactful practical example strategy. This program would address the issue of water scarcity and provide a scalable model for other regions facing similar challenges. By demonstrating the economic and environmental benefits of wastewater recycling, such an initiative could help farmers adopt circular practices while contributing to sustainable agriculture's broader goals.

In conclusion, implementing large-scale, long-term mechanisms to engage the younger generation in agriculture and transforming traditional farming systems into modern, commercial enterprises is essential for advancing the circular economy in agriculture. Through targeted agricultural education and extension programs, coupled with practical examples such as wastewater recycling, the transition to a circular agricultural system in Kurdistan can be facilitated, offering a sustainable path forward for the region and beyond.

It is important to acknowledge that while the ISM approach effectively identifies key barriers, it has limitations, such as its reliance on expert opinions, which can introduce subjectivity, and the absence of quantifiable measures of relationship strength between variables. To provide a more comprehensive understanding of the challenges and opportunities in circular agriculture, future research should consider complementing ISM with additional methodologies, such as structural equation modeling or systems dynamics, to capture both the quantitative relationships and the complex interactions within the system.

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Author Contributions

Mahmood Haji-Rahimi served as the principal investigator and lead author of this study. Kiana Bahmanzad contributed to data collection, conducted interviews, and prepared the calculation model in Excel. Dr. Hamed Ghaderzadeh assisted in developing the model and identifying key factors for the study.

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Competing Interests

The authors have declared that no competing interests exist.

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