New Business Model Proposal in the Digital Age: Sustainability-Focused Servitization

Abstract

Purpose: With the pressure of global markets and demanding customers, most production companies are moving from pure production to the integration of products and services. This new formation is known as servitization and can give companies a strong competitive advantage. The recent studies in the literature proposes that servitization has a positive impact on sustainability by improved energy consumption. However, they also underscored the need for better implementation of sustainability and the barriers avoiding sustainable servitization behavior. This research aims to investigate sustainability-oriented servitization barriers, which have not taken any attention by previous research, and their relationships for successful implementations.

Design/methodology/approach: We extracted fifteen servitization barriers from the literature and a focus group study. Then we presented their relationship with sustainable dimensions such as human, business, economic and market, and environment. Using the selected experts' assessments, we implemented Fuzzy-TISM to analyze the causal relationship among the barriers. We also implemented Fuzzy-MICMAC analysis to categorize the barriers.

Findings: The findings presented that lack of understanding of customer, cultural problems, high market risk, financial constraints, lack of environmental awareness, and lack of environmental regulations are independent variables and play a very critical role in the success of sustainable-servitization implementations. Finally, we proposed several managerial insights and a structured hierarchical model that can be used as a guide by practitioners to develop a better strategy for their implementations.

Originality/value: To the best of our knowledge, a detailed examination of the barriers and challenges in the triple bottom line approach is already missing at the desired level. From this point of view, this study is the first research that determines barriers of servitization based on the triple-bottom-line model with a sustainability perspective.

Keywords: Digitalization, Servitization, Sustainability, Fuzzy-TISM, Barriers

1. Introduction

Due to the increasing competition day by day, the globalization of the market and the increasing consumer demand, most production companies are moving from pure production to the integration of products and services. This integration has been assessed in the literature under the different names such as servitization (Neely, 2008; Matinez et al. 2010; De Jesus Pacheco et al. 2019); integrated solution (Davies et al. 2007); product service system (Tukker and Tischner 2006; Michalik et al. 2019) and tertiarization (Sforzi&Boix, 2019). Many companies recognized the potential source of revenue and differentiation opportunities in servitization

process so recently it has been an essential issue of the researchers and practioners. Although it is called under different names in the literature, it is the process that creates a competitive advantage and consists of a system that includes products, services, and a combination of both. Therefore, the general definition of the servitization is that manufacturers provide additional services to their customers throughout the entire life cycle of the product (Oliva and Kallenberg, 2003; Kühl et al. 2019). Installation, maintenance, repair and even renewal of the product purchased from the manufacturer are all included in this type of service. The fact that companies offer different services together with the products they sell contributes to them in many ways such as encouraging optimization of resource use by increasing productivity (Vezzoli et al. 2015), extending product life (Reim et al. 2015) or reducing the total number of products in use. In addition to its ability to create competitive benefits, it is clear that servitization can also help companies meet their environmental and social needs (Beuren et al. 2013; Annarelli et al. 2016; Szasz and Seer, 2018). Thus, sustainability-oriented servitization plays an important role in ensuring the competitiveness of companies.

In spite of the sustainability-oriented servitization's benefits, implementing this new business model is challenging. There are some studies in the literature that show that there are difficulties that prevent this new business model from being delivered in a sustainable way (Hernandez-Pardo et al. 2012; Vezzoli et al. 2015; Kjaer et al. 2016). There are some initial attempts for determining barriers of servitization (Hou and Neely, 2013; Oschmann et al. 2012; Michalik et al. 2019). Even though there are plenty of studies that mention the drivers of servitization, none of them included the three pillars of sustainability: environmental, economic and social dimensions at the same time. Therefore, to the best of our knowledge, a detailed examination of the barriers and challenges in the triple bottom line approach is already missing at the desired level. As explicitly mentioned here, there is a major gap in the literature on this subject. Therefore, this study has two main motivations. First, not only to identify servitization barriers from a sustainability perspective, but also to examine these three basic headings under the basic headings of business and marketing. Then, due to the dynamic nature of these identified basic preventive approaches, it is necessary to analyze the cause-effect relationships between them and present a roadmap. From this point of view, this study is the first research that determines barriers of servitization based on the triple bottom line model with a sustainability perspective. As a result, the research questions of the study can be summarized as;

- What are the main barriers and challenges for sustainability-oriented servitization in emerging economies?
- How shall we analyze and figure out the relationship among the criteria of the sustainability-oriented servitization?
- Could a sustainable servitization roadmap be developed as a guide for practitioners?

In order to find answers to these questions, first of all, a detailed literature review and a focus group discussion will be conducted to find the significant barriers of sustainability-oriented servitization. The identified barriers are then categorized under the dimensions of the triple bottom line (TBL) approach with a little variation such as human, business, economic and market, and environment. Lastly, Fuzzy-Total Interpretive Structural Modelling (TISM) method is used. Fuzzy-TISM is one of the multi-criteria decision-making techniques that analyze the casual relationship among the variables for guiding future implications.

This study is structured as follows; the next section presents sustainable servitization discussions, the servitization barriers and challenges mentioned in previous studies, and their relations with sustainability. Section 3 consists of the research methodology implemented for analyzing the identified barriers. Section 4 consists of the findings obtained from the implementation of Fuzzy-TISM and MICMAC analysis, as well as several managerial insights. Last, the conclusion is provided in section 5 with discussions, limitations and future directions.

2. Sustainable Servitization

Recently there have been lots of articles in the fields of servitization. The articles generally focus on service-dominant logic (SDL), service innovation, and service operations (Rabetino et al. 2018). A total of 21 studies on sustainable servicing have been carried out since 2015 (De Jesus Pacheco et al. 2019). It contributes to sustainability due to the approach to servicing, lower material use, and energy consumption. However, the sustainability issue, which has come to the fore lately, does not attract enough attention. Therefore, there are gaps in the literature regarding servitization and sustainability.

Most of the studies conducted are aimed at examining generally just one dimension of sustainability or determining the sustainability effect on servitization. Servitization enables companies to be sustainable by reducing social and environmental problems by keeping the economy in balance (Menon et al., 2024). Therefore, servitization provides the opportunity to achieve better environmental performance by developing an integrated product, service, and

communication system in the medium and long term (Beuren et al., 2013) to increase the value of the product. However, there are gaps in the literature regarding servitization and sustainability. Most of the studies conducted are aimed at examining generally one dimension of sustainability.

Financial perspective of servitization shows that an increase in applying servitization intensity brings benefits to companies in terms of growth in sales and profitability (Kohtamaki et al. 2015; Zghidi and Zaiem, 2017). However, some studies mention that the risk of bankruptcy may increase (Benedettini et al. 2015) and the life expectancy of companies will shorten (Ulaga and Loveland, 2014) in financial terms. Contrary to the positive and negative effects of servitization in financial terms, it has been observed that it has a positive effect on the environment such as decreasing product turnover (Kastalli and Van Looy, 2013), remanufacturing products, increasing product life cycle (Doni et al. 2019).

There are also some studies in the literature in which only one dimension of sustainability was studied. As seen in Table 1, some studies investigated the effect of sustainability in servitization. Marić and Opazo-Basáez (2019) determined the relationship between green servitization and reverse logistics activities. Pinto et al. (2019) studied servitization from a different perspective. They focus on sustainable cities with challenges of the servitization. Doni et al. (2019) merged corporate sustainability with servitization in manufacturing companies. But, none of these studies are determined the relationship between servitization with triple bottom line perspective.

Table 1. Studies on sustainable servitization with different perspective. (Source: Authors own work.)

Aim of the study	**Author(s)**
Assess the impact of servitization on sustainability in European manufacturing companies by investigating corporate sustainability disclosure, environmental performance, and policies.	Doni et al. (2019); Saygili et al. (2022)
Explore the relationship between reverse logistics and sustainable development objectives from the standpoint of green servitization.	Marić and Opazo-Basáez (2019)
Understand how servitization helps sustainable cities, but also determine the contributions and challenges of the service-providing model.	Pinto et al. (2019)
Build and validate an operations strategy model of servitization confirming previous case study findings on servitization as a strategic action and to explore the role of sustainability pressures.	Szasz and Seer (2018)

It is not easy for companies to adapt servitization model that may provide several advantages such as increasing company profits, decreasing costs, and moving to core business areas. Companies face serious barriers in implementing this new business model. It is necessary to know these enablers in advance and to take measures in a way that does not disturb the internal functioning of the company. As mentioned before, although servitization has received a lot of attention by researchers, there are few studies that focused on determining possible barriers of sustainable servitization.

Hou and Neely (2013) are the first to describe a list of barriers of servitization in the literature. They categorized barriers under seven groups such as competitors, suppliers & partners; customers; finance; knowledge & information; products & activities; organizational structure & culture; society & environment. They argued that financial barrier has received the most attention from companies. Oschmann et al. (2012) identified barriers from medium sized manufacturer's perspective. The author expanded the list by adding strategy & development barrier to Hou and Neely (2013)'s list. Oschmann et al. (2012) claimed that internal barriers weights are much more than external ones. Lütjen et al. (2017) categorized servitization barriers into strategy, implementation and market related groups. Michalik et al. (2019) analyzed barrier list of the Oschmann et al. (2012)'s within the Dortmund Management Model (DMM) for small and medium sized manufacturing enterprises. At the end, they claimed that organizational, strategic and personnel barriers are important in the servitization.

As seen in the abovementioned previous studies, none of the existing studies for servitization considered the barriers with the triple bottom line perspective of sustainability. Therefore, the barriers to companies transitioning to a sustainable servicing process are still not fully defined. The next section consists of identifying these barriers and grouping them with a triple bottom line perspective.

2.1. Sustainable-Servitization Barriers

As mentioned in the previous section, identifying barriers to servitization is very important for companies. Although there are some studies about determining the barriers to the servitization, none of these studies examined servitization in terms of the dimensions of sustainability, which are human, business, economic and market, and environmental dimensions. The first research question of this study is to determine the barriers to sustainable servitization based on the triple bottom line perspective. Therefore, first of all, a detailed literature review was made to identify

the barriers. Then, the determined barriers were reviewed by the focus group. In many complex qualitative studies, the Delphi method has been employed to reach a consensus between a group of experts using a systematic way (Giannarou and Zervas, 2014). Hence, we employed the Delphi method to finalize the list of barriers and elucidate the relationship between them. The detailed information about the implementation of the Delphi method and the characteristics of the selected experts are given in section 5. The identified nineteen barriers are given in Table 2. Except for the barriers B9 and B10, the selected barriers were extracted from the literature. These barriers are briefly described under the sustainability dimensions in the following subsections.

Table 2. Sustainable servitization barriers with respect to sustainability dimensions.(Source: Authors own work.)

Sustainable Dimension	**Code**	**Barriers**	**Author(s)**
Human	B1	lack of understanding of customer	Oschmann et al. (2012); Raja et al. (2017); Klein et al. (2018)
	B2	lack of skilled worker	Lerch and Gotsch (2015); Süße et al. (2018)
	B3	problems with suppliers & partners	Hou and Neely (2013), Bustinza et al. (2024)
	B4	problems to spread responsibilities	Maxwell et al. (2006); Sundin et al. (2015)
Business	B5	problems for adapting new technology	Martinez et al. (2010); Lerch Gotsch (2015); Paschou et al. (2018); Mittal et al. (2018); Michalik et al. (2019)
	B6	organizational problems	Hou and Neely (201)3; Matt et al. (2015); Kane et al. (2015); Pieroni et al. (2016); Klein et al. (2018)
	B7	cultural problems	Hou and Neely (2013); Von Leipzig et al. (2017)
	B8	lack of strategic orientation	Oschmann et al. (2012); Ambroise et al. (2018)
	B9	unfavorable characteristics of the products and services	Experts'choice
	B10	complexity of the service delivery	Experts'choice
Economic & Market	B11	high market risk	Meyer (2013); Clegg et al. (2017); Faisal (2023)
	B12	high investment cost	Hernandez-Pardo et al. (2012)
	B13	financial vulnerability	Gebauer et al. (2010); Rapitsenyane (2014)
	B14	financial constraints	Kowalkowski et al. (2013)
	B15	difficult to price service	Michalik et al. (2019); Singh et al. (2024)
Environment	B16	lack of environmental awareness	Rapitsenyane (2014); Sundin et al. (2015)
	B17	problems in green service	Nunes and Bennett (2010); Gunasekaran and Spalanzani (2012)
	B18	lack of green management	Mittal and Sangwan (2014); Ranta et al. (2018)
	B19	lack of environmental regulations	Hernandez-Pardo et al. (2012); Peillon and Dubruc (2019)

2.1.1. Human Dimension

Although it makes use of different machines and technologies in the servitization, the human dimension constitutes the basic building block. In order for the systems to work efficiently, the needs, responsibilities, and abilities of all persons involved must be clearly stated. As companies generally define the human dimension only as customers, they always face barriers in the servitization. Four main human-induced barriers to servitization have been identified.

Lack of skilled worker: It is very difficult to find qualified employees to meet customers' endless and diverse service expectations. Workers are also expected to have the necessary skills and capabilities (Meyer, 2013).

Problems with suppliers & partners: It is hard to get the coordination and cooperation from different actors during the service period. These actors have a problem to accept the new process due to their behaviors and usage habits (Hou and Neely, 2013).

Problems to spread responsibilities: There will be a problem to share responsibility between the provider and the end-user. When a problem is encountered, it should be stated who should be consulted for a solution (Sundin et al., 2015). The responsibilities of each actor in the system must be clearly defined.

2.1.2. Business Dimension

We identified the following five barriers that are related to the business dimension of sustainable servitization.

Problems for adapting new technology: Different technologies may often be required to meet customer needs. However, employees who are used to traditional working conditions find it difficult and resilient to adopt these new technologies (Michalik et al. 2019).

Organizational problems: The literature on servitization shows no consensus concerning the characteristics of an optimal organizational design (Ambroise et al. 2018). Therefore, companies that implement a service strategy should adapt their organizational structures and processes according to their own dynamics.

Cultural problems: Internal resistance to change is one of the biggest barriers to servitization. Lack of coherence in mentality makes it difficult to move things forward. Cultural problems related to innovation, change management, agility, cooperation, leadership, problem-solving, etc.

Lack of strategic orientation: Failure to fully define the strategic goal can cause problems within the company. Therefore, senior management should adopt a sensitive, consistent, and sustainable management approach.

Unfavorable characteristics of the products and services: The product or the service might be new, very individual, or infrequently demanded. Besides, it may have a short life cycle, low commodity content, or high obsolescence rate. Therefore, such characteristics of the products play a critical role in adopting servitization strategies.

Complexity of the service delivery: Similar to the characteristics of the products, how they are produced, how much customers want to involve in production and delivery, or how the products or services are delivered to customers in the network may also create some barriers for the servitization. For instances, the services that are required to be delivered at many different locations or across multiple channels, or that requires a high number of feedback loops or a high variety of technologies cause a high level of challenges for providing servitization (Demirkiran et al.,2022).

2.1.3. Economic and Market Dimension

Companies recognize that additional services provided through servitization are a potential source of income and that their average earnings will increase significantly. But, economic barriers are assumed to be one of the main driving forces behind a company's decision to adopt a servitization strategy (Gebauer et al. 2010).

High market risk: Market risk is the risk that the value of an investment will decrease due to changes in market factors (Benedettini et al., 2015). Such findings raise doubts about the overall performance of the company and its impact on the value creation process of providing servitization.

High investment cost: This feature is related to a lack of financial competence for an initial investment. The long and/or uncertain depreciation period of the investment is also a major barrier for servitization.

Financial Vulnerability: Servitization, which is the combination of product-service offerings, can cause volatility and fragility of cash flows over the life of a product. Therefore, companies postpone providing such services.

Financial constraints: Financial constraints affect companies' medium and long-term investment decisions. Therefore, the lack of financial resources and undefined financial performance metrics are some of the major barriers to servitization.

Difficult to price service: Product-service providers have to use a different pricing strategy than traditional product pricing. The complexity of various services, the length of service life, and the uncertainty of the content, the variety of customers' needs and expectations create difficulties in determining appropriate pricing or pricing strategies (Kastalli & Van Looy, 2013).

2.1.4. Environment Dimensions

Many product-service providers unfortunately only focus on costs and profits while ignoring environmental damage. However, they must be sensitive to environmental issues for their service to be sustainable.

Lack of environmental awareness: Most companies lack knowledge and awareness of environmental issues. Therefore, environmental awareness is seen as a cost for many companies. However, product transformation speed is decreasing in the servitization business model. Thus, companies see this as a barrier to be overcome.

Problems in green services: This feature refers to the problems faced by sustainable entrepreneurs who aim to achieve cleaner production and service methods. With servitization, some services may cease to be more environmentally sensitive.

Lack of Green management involvement: To ensure that the services are sustainable; companies must be sensitive to environmental problems. Therefore, it should be an obligation, not a barrier, for senior management to adopt a consistent green management approach. Some managers do not lean towards servitization, as they think they will move away from the consistent environmental awareness they have adopted.

Lack of environmental regulations: Lack of environmental regulations: The priority of the servitization business model is to reduce cost items. The positive impact on the environment

ranks lower in servicing. This feature is the barrier faced by companies that provide services that are more environmentally sensitive due to the lack of policy and infrastructure support.

To understand the structure and propose managerial implications for sustainability servitization, it is essential to analyze the relationship between each barrier. In the next sections, the identified sustainable servitization barriers are being deeply analyzed to explore the relationship among them to develop a strategical roadmap to decision-makers who would like to adopt servitization in their business.

3. The Proposed Model for Analyzing Sustainable-Servitization Barriers

Considering sustainability servitization, it is essential to focus on business environmental and economic impacts. This study has three main research questions; (1) to determine the significant barriers for sustainability-oriented servitization, (2) to figure out the relationship among those barriers, and (3) to develop a hierarchical sustainable servitization roadmap for practitioners.

To find the answers to these questions, we proposed an integrated model. An appropriate method is required to analyze the structural complex relationships between the sustainable servitization criteria and triple bottom line dimensions. The first and most critical step is to determine a list of sustainable servitization barriers that are expected to have a significant effect on implementation. For this purpose, the previous studies and experts' opinions could be a valuable source of determining the barriers. Mostly, there are many different criteria or barriers identified for the problem, of which some might be conflicting the others might be dependent or independent. Next, an appropriate method is required to analyze the structural complex relationships among the barriers because determining the relationships among various and conflicting criteria is very important for a better decision-making process (Nasim, 2011). Although there are several methods for presenting interactions between criteria, many of them are not capable of providing a hierarchical relationship among criteria for deeper insights. Therefore, in this study, Fuzzy-TISM method was used to determine the causal relationships between sustainable servitization barriers. Figure 1 demonstrates the flow of the proposed integrated model for answering our research questions. Each step of the proposed model and how it is implemented are explained in the following sections in detail.

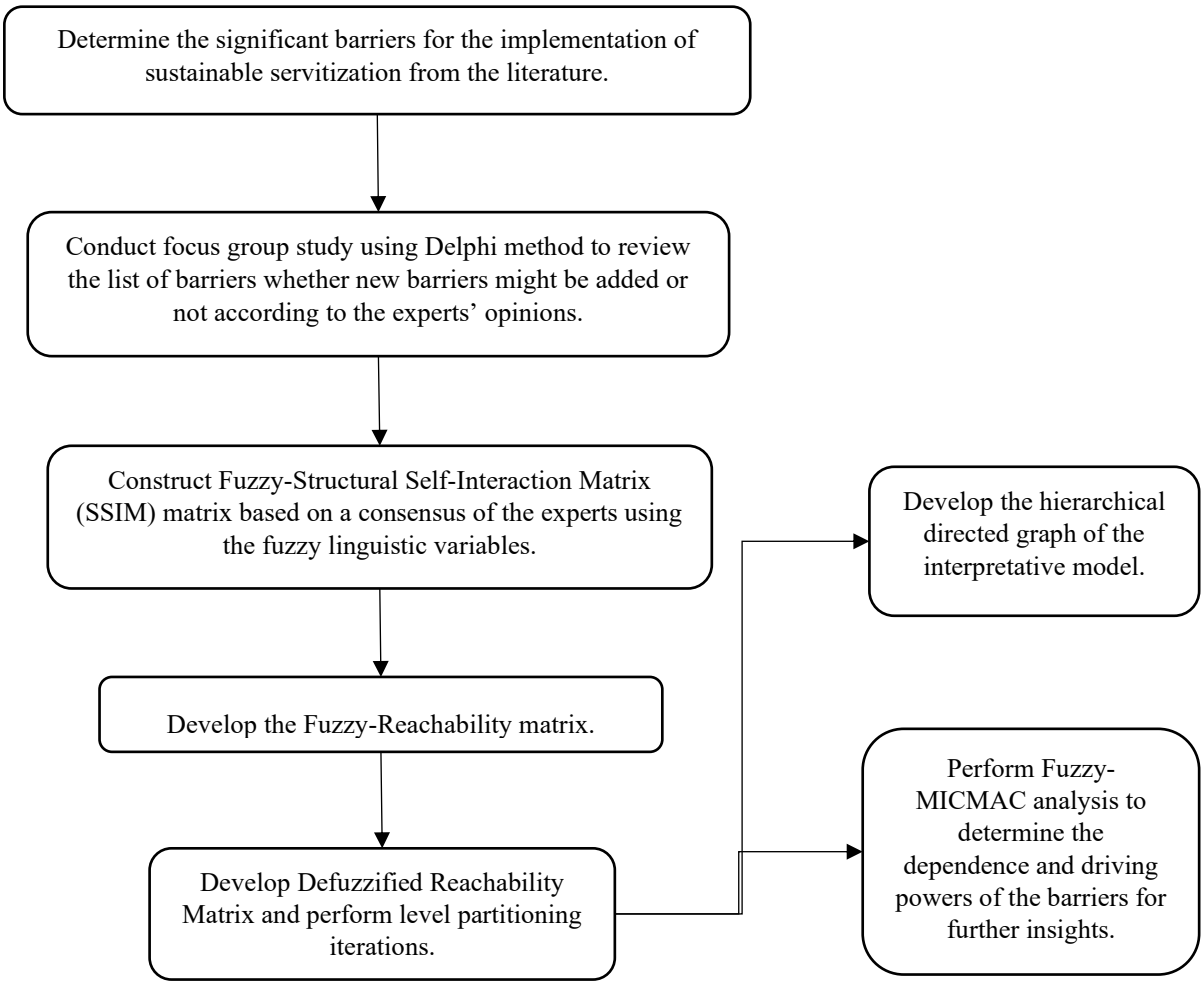

Figure 1. The adopted methodology to derive interpretative model of the sustainable servitization barriers. (Source: Authors own work.)

3.1. Fuzzy-Total Interpretative Structural Modeling with MICMAC Analysis

Interpretative Structural Modeling (ISM) model proposed by Warfield (1974) helps researchers to answer "what" and "how" questions in research providing a graph of the relationship between elements according to experts' thoughts. Sushil (2012) took ISM further and proposed Total Interpretative Structural Modeling (TISM) to answer "why" in research. Hence, TISM accomplishes to answer the logic behind the interrelations of the elements in addition to their essence and relationship. The hierarchical map of the relationship between elements of a problem developed by TISM provides an explanatory framework to address the challenges, barriers, and enablers. Table 3 presents a list of some of the recently published research that used TISM for analyzing the challenges of barriers to an issue. A detailed list of studies that used TISM and published before 2017 could also be seen in Sushil (2017)'s review. As seen in the literature, TISM method is very commonly supported by MICMAC analysis to determine

the dependence and driving powers of the elements. Even though ISM and TISM have been intensely used methods, Fuzzy-ISM and Fuzzy-TISM have been recently paid attention by the researchers to involve vagueness of information within decision-making processes using fuzzy numbers (see Table 3 for example studies). Hence, Fuzzy-TISM facilitates the use of linguistic and logical variables by decision-makers when evaluating the causal relationship between them. Because of its strength in the analysis, we also implemented Fuzzy-TISM in our research. The adopted procedure to implement Fuzzy TISM was depicted in Figure 1 and explained in the following subsections.

Table 3. The list of some recent studies that implemented TISM and Fuzzy-TISM in analyzing challenges, barriers or enablers. (Source: Authors own work.)

References	Field of Study	Model
Ajmera and Jain (2019)	Barrier analysis to the adoption of Health 4.0 applications	TISM with MICMAC analysis
Patil et al. (2018)	Barrier analysis to the implementation of sustainable solid waste practices	TISM with MICMAC analysis
Mohanty and Shankar (2017)	Analyzing the sustainability enablers for integration of logistics activities such as transportation, warehousing, information technology etc.	Fuzzy-TISM with MICMAC analysis
Bamel et al. (2021)	Analyzing inter-partner dynamics-based enablers of joint venture competitiveness	Fuzzy-TISM with MICMAC analysis
Jain and Soni (2019)	Identifying the relationship between flexible manufacturing system performance factors	Fuzzy-TISM with MICMAC analysis
Khan et al. (2019)	Analyzing the initiatives for the harmonization of Halal standards to eliminate trade barriers of Halal goods	Fuzzy-TISM with MICMAC analysis, and Interpretative Ranking Process
Bag (2017)	Analyzing the enablers of successful green procurement practices	Fuzzy-TISM with MICMAC, Fuzzy-DEMATEL
Virmani et al. (2018)	Analyzing the inter-relationship of key performance indicators for leagile (lean+agile) manufacturing systems	Fuzzy-TISM with MICMAC
Lamba and Singh (2018)	Analyzing the critical enablers of big data initiatives for the success of operations and supply chain management	Fuzzy-TISM with MICMAC, and DEMATEL
Kaur (2019)	Analyzing the enabling factors of redesigning IoT-driven sustainable food security system considering various Technologies and their applications in various levels of policy implementation	Fuzzy-TISM with MICMAC

3.1.1. Fuzzy-Structural Self-Interaction Matrix (SSIM)

Structural Self-Interaction Matrix (SSIM) is the core element of both ISM and TISM. SSIM elucidates the contextual relationship between every pair of barriers using the following predefined four symbols V, A, X, and O by Sushil (2012). Then, in a typical ISM and TISM, the crisp entries of (i,j) and (j,i) in the SSIM are respectively determined.

- V: Barrier i helps to achieve barrier j, but barrier j does not help to achieve barrier i. Hence, (i,j) and (j,i) take 1 and 0, respectively.

- A: Barrier j helps to achieve barrier i, but barrier i does not help to achieve barrier j. Hence, (i,j) and (j,i) take 0 and 1, respectively.
- X: Barriers i and j help each other. Hence, (i,j) and (j,i) both take 1.
- O: Barriers i and j do not help each other (unrelated). Hence, (i,j) and (j,i) both take 0.

In fuzzy theory developed by Zadeh (1965), the variables are described by fuzzy sets, which are declared as to be close to human thinking, with appropriate membership functions. In this study, we implemented five fuzzy linguistic variables with triangular fuzzy membership function as demonstrated in Table 4 in accordance with Khatwani et al. (2015). The triangular fuzzy membership function of concept class A with an element of x ($\mu_A(x)$) is represented by a triplet (l,m,u), where l,m,u are lower, mode, and upper values of the fuzzy numbers (see Figure 2 for the representation).

Table 4. The fuzzy linguistic scale. (Source: Khatwani et al. (2015))

Linguistic terms	**Triangular fuzzy numbers** (i,j)
Very high influence (VH)	(0.75,1.0,1.0)
High influence (H)	(0.5,0.75,1.0)
Low influence (L)	(0.25,0.5,0.75)
Very low influence (VL)	(0,0.25,0.5)
No influence (No)	(0,0,0.25)

$$\mu_A(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases}$$

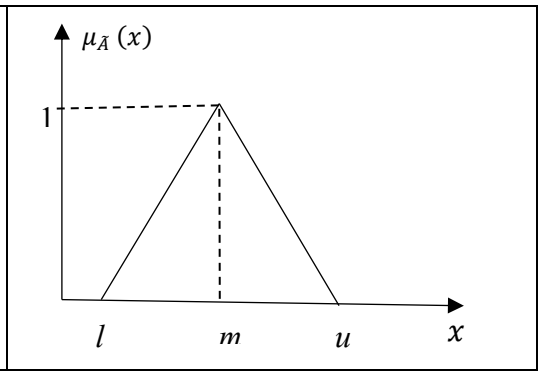

Figure 2. Triangular fuzzy membership function. (Source: Authors own work.)

The experts' opinions are used to evaluate the relationship between a pair of barrier and the degree to what extent a barrier has an influence on another. For each forward comparison, one of the four symbols of the contextual relationship (V, A, X, or O) and an appropriate fuzzy linguistic scale (No, VL, L, H, or VH) are used to generate Fuzzy-SSIM. For instances, if barrier i is declared to have a V relationship and High (H) influence on barrier j, the entry of (i,j) in Fuzzy-SSIM is denoted as V(H). Similarly, the entry X(VH,L) denotes that barriers i and j influence each other whereas barrier i has a Very High influence on j, and barrier j has a Low

influence on i. Last, by consensus, the aggregated Fuzzy-SSIM is developed when every pair of relation is reviewed.

3.1.2. Fuzzy-Reachability Matrix

The aggregated Fuzzy-SSIM is transformed into fuzzy reachability matrix evaluating every reverse relationship of (i, j) pairs. Then, the linguistics terms are converted into fuzzy numbers. For an instance, the entry of (j, i) is determined as O(No) if (i, j) is V(H); hence the fuzzy numbers of (i, j) and (j, i) are denoted as (0.5,0.75,1.0) and (0,0,0.25), respectively. Additionally, the entry of (j, i) is X(L,VH) if (i, j) is X(VH, L); hence the entry of (i, j) and (j, i) in the fuzzy reachability matrix are denoted as (0.75,1.0,1.0) and (0.25,0.5,0.75), respectively. Simply, if a relation is described as V or A, its reverse is denoted as O(No). If a relation is defined by X, the expert should define the significance of either way relation. If only one fuzzy term is used it is assumed to be valid for either direction. Last, if the entry is O(No), the other direction is also denoted as O(No). We kindly refer Khatwani et al. (2015) for a very detailed explanation of the reverse of each relation and a fuzzy term to construct fuzzy reachability matrix. As a consequence, the final fuzzy reachability matrix A is obtained.

$$A = \begin{bmatrix} A_{11} & A_{12} & \dots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \cdots & \cdots & \dots & \cdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix}, \text{ where } A_{ij} = (l_{ij}, m_{ij}, u_{ij}) \text{ and } n \text{ is the number of barriers.}$$

3.1.3. Defuzzification of Fuzzy-Reachability Matrix and level partitioning

In order to perform transitivity check and level partitioning steps, fuzzy numbers in the final Fuzzy-Reachability Matrix should be converted into crisp values. Thus, similar to Khatwani et al. (2015), we defuzzify values by assigning 1 crisp value to Very High (VH) and High (H) Influences, and 0 to other relations. Then, the transitivity rule is checked and applied when needed through the whole defuzzified reachability matrix until full transitivity is established.

The transitivity is the connection among three variables such that if a connection exists between barriers i and j and a connection exists between barriers j and k then barriers i and k should also be linked to high consistency. If any pair of relation violates this transitivity rule, it is fixed and transitivity is represented as 1*.

Using the finalized defuzzified reachability matrix, level partitioning is performed to determine reachability and antecedent sets of barriers for developing a structural model. The reachability set of a barrier includes itself and the other barriers, which it may help to achieve and are located in its row. The antecedent set of a barrier consists of itself and the other barriers, which may help to achieve it and are located in its column in the matrix. First, the reachability and the antecedent sets and their intersection are computed for every barrier. Then, level partitioning is conducted by following the steps: (1) the barriers that have the same intersection and reachability sets are located at the top of the structural model; (2) these barriers are removed from the reachability matrix (their rows and columns are deleted) and moved to the next bottom level; (3) the reachability, antecedent, and intersection sets are computed for the remaining barriers; (4) the previous steps are repeated until all barriers are partitioned into levels.

3.1.4. Developing Directed Graph of the Structural Model

The directed graph or digraph demonstrates the interrelationship among the barriers that were leveled in the previous step. In a digraph, nodes represent the barriers and arrows indicate their relationship. Starting from the lowest level, the barriers are located in a hierarchical way. Then, the transitive links among the same level barriers and their antecedents are indicated according to the reachability matrix. The final digraph is converted into the interpretative structural model of the barrier analysis and is used to develop appropriate policies for decision-makers.

3.1.5. Fuzzy-MICMAC Analysis

MICMAC (Matriced Impact Croises Multiplication Applique) is an analysis that helps decision-makers to understand the characteristics of the variables. MICMAC analyzes the driving and dependence powers of the barriers considering the binary relationship among them (Duperrin and Godet, 1973; Caliskan et al., 2022). Based on their powers, it aims to reveal the key variables that drive the system in the following categories. It then demonstrates barriers in each category in a four-quadrant graph.

i) Autonomous barriers: These barriers generally have the fewest number of transitivity links and relatively disconnected from the system. These barriers have weak dependence and weak driving powers. They are located at the Quadrant-I in the graph.

ii) Dependent barriers: These barriers are identified as their strong dependence power but weak driving power. They are located at the Quadrant-II in the graph.

iii) Linkage barriers: These barriers have both strong driving and dependence powers. Hence, they are considered as critical and unstable variables in the system because of their significant effect on other barriers as well as on themselves. They are located at the Quadrant-III in the graph.

iv) Independent barriers: These barriers have strong driving power and weak dependence power. They are located at the Quadrant-IV in the graph.

We employed one of the most commonly used defuzzification methods called CFCS (Converting Fuzzy data into Crisp Scores) method initially proposed by Opricovic and Tzeng (2003) to obtain crisp values from fuzzy numbers for computing driving and dependence powers of the barriers in Fuzzy-MICMAC analysis. The following steps explain how to calculate crisp values of the driving powers using the evaluations in Fuzzy-Reachability Matrix. To calculate the dependence powers,

Step 1: Compute fuzzy dependence and driving powers:

Fuzzy Driving Powers of barriers i: $A_i = (l_i, m_i, u_i) = (\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij})$

Fuzzy Dependence Powers of barriers j: $\tilde{A}_j = (\tilde{l}_j, \tilde{m}_j, \tilde{u}_j) = (\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij})$

Step 2: Compute the normalized lower, mode and upper values. The equations given hereafter for computing the driving powers. Replacing the appropriate terms with $(\tilde{l}_j, \tilde{m}_j, \tilde{u}_j)$, the readers could easily compute the terms for the dependence power. Let L, R and Δ be the maximum, minimum and the range of the fuzzy numbers, respectively. Let x_i^l, x_i^m and x_i^u be the normalized lower, mode and upper values, respectively.

$$L = \min l_i, R = \max u_i, \ \Delta = R - L$$

$$x_i^l = (l_i - L)/\Delta, x_i^m = (m_i - L)/\Delta, x_i^u = (u_i - L)/\Delta$$

Step 3: Compute the normalized left and right scores: x_i^{ls} and x_i^{rs}, respectively.

$$x_i^{ls} = x_i^m / (1 + x_i^m - x_i^l); \ x_i^{rs} = x_i^u / (1 + x_i^u - x_i^m)$$

Step 4: Compute the total normalized crisp value of the driving (dependence) power of barrier i:

$$\ddot{x}_i = \left[x_i^{ls} \cdot \left(1 - x_i^{ls}\right) + x_i^{rs} \cdot x_i^{rs}\right] / [1 - x_i^{ls} + x_i^{rs}]$$

Step 5: Compute the crisp value of the driving (dependence) power of barrier i: $x_i = L + \ddot{x}_i \cdot \Delta$

4. Implementation

This section explains the implementation of the proposed methodology in Figure 1. The criteria have been identified based on the literature review and in a focus group study. In many complex qualitative studies, the Delphi method has been employed to reach a consensus between a group of experts using a systematic way (Giannarou and Zervas, 2014). Hence, we employed the Delphi method to finalize the list of barriers and elucidate the relationship among them in the focus group study.

First, as discussed in section 2, we identified a list of sustainable servitization barriers from the previous studies (see Table 2 for the barriers and the references). We then selected a group of seven experts to discuss the significance of the identified barriers from the literature. The experts were selected from academia and the industry who have at least 10 years of experience in production and operations, marketing, and innovation management. Their profiles are given in Table 5 in detail. We also would like to note that the selected academicians have been actively involved in industrial projects. Next, we emailed the experts the list of barriers with their explanations and our goal in this research . We then emailed the experts a list of barriers along with their explanations and our goal for this research. After this initial email, we gave them one week to learn details about the topic. Exactly one week later, we held an online meeting with all the experts. In this online meeting, we asked the experts two basic questions; whether any of the barriers were irrelevant to our purpose and whether an additional barrier should be included. The meeting lasted one hour and forty-five minutes. Under our guidance and facilitation, the experts agreed on a list of identified barriers and introduced two additional business-related barriers: (1) unfavorable characteristics of products and services and (2) complexity of service delivery. These barriers are shown earlier in Table 2 and explained in Section 2 for the sake of flow.

Table 5. The profile of the selected experts. (Source: Authors own work.)

Expert	Academia /Industry	Field of Study/Area	Institution	Years of Experience	Current Role
#1	Academia	Production and Operations Management	Private University	17	Associate Professor
#2	Academia	Innovation Management	Public University	28	Professor
#3	Academia	Marketing	Private University	18	Associate Professor
#4	Academia	Sustainable Operations Management	Private University	18	Professor
#5	Industry	Production and Marketing	Internationally owned big-sized manufacturing company of wheels	25	Marketing Director
#6	Industry	Production and Information Systems	Nation-wide big-sized manufacturing company of machine parts	21	Director of Digitalization
#7	Industry	Marketing and Management	Internationally owned big-sized manufacturing company of healthcare products	12	Chief of Marketing Officer

After finalizing the list of barriers, we designed a questionnaire to facilitate the data collection process for pairwise comparisons. After we collected the questionnaires, we calculated the mode of each comparison. In the second round of our online meeting, we posed the mode values of each pairwise-comparison to discuss if we could get a consensus on the evaluations. The threshold criterion for consensus was defined as the 75 percent of the agreement (five agreements out of seven in our study) because Diamond et al. (2014) revealed that the percentage agreement is the most commonly used criterion with a median threshold value of 75% after reviewing 72 studies in the literature in the Delphi method. At the end of our meeting, we obtained the final Fuzzy Structural Self-Interaction Matrix (SSIM), which is the main input for the analysis of servitization barriers using Fuzzy-TISM, by consensus as shown in Table A1.

Table A1 shows the suggested relationships in consensus, i.e. there is no relationship between "Lack of understanding of customer (B1)" and "Lack of environmental regulations (B19)". Moreover, whereas the barrier B1 is seen to have a low influence (L) on achieving the barrier "lack of green management (B18)", the barrier B18 has no influence on the barrier B1. We also see that while the barrier B1 has a high influence on achieving "Problems in green service (B17)", the barrier B17 also influences the barrier B1 but at a very low level.

Based on the discussions provided in section 3.1.2, the aggregated Fuzzy-Reachability Matrix with linguistic variables was developed as in Table A2 from the Fuzzy-SSIM in Table A1. This

table demonstrates every pair of relations among the barriers explicitly. The corresponding Fuzzy-Reachability Matrix with fuzzy numbers is also given in Table A3. The fuzzy numbers in this table is later used to perform Fuzzy-MICMAC analysis.

In order to develop the structural relationship among the barriers, we defuzzified Fuzzy-Reachability Matrix given in Table A2 and verified its transitivity using the procedures discussed in section 3.1.3. Thus, Defuzzified Reachability Matrix with full transitivity was developed as in Table A4. In accordance with the presented steps in section 3.1.3 and using Table A4, level partitioning was carried out to demonstrate the barriers' level-wise relationship. Table 6 presents the level of the barriers identified at each iteration, their reachability and antecedent sets. It can be seen for these barriers that the intersection of their reachability and antecedent sets are the same as their reachability set. Thus, these barriers are located at the top level of the structural directed graph demonstrating that they would not help to achieve the barriers below their own level. For instances, "Problems to spread responsibilities (B4)", "Financial vulnerability (B13" and "Difficult to price service (B15)" are positioned at the top of the hierarchical directed model and they would not help to achieve all other barriers.

Using the outputs of the level partitioning process, we demonstrated the hierarchical interpretative structural model of the servitization barriers in Figure 3. The barriers and their relationships are represented nodes and arrows in the digraph, respectively. While the barrier (B11) is located at the bottom (Level 8), the barriers B13, B4, and B15 are located at the top. Considering the two-way relationships in Table A2, we depict only "Very High" and "High" level relationships among the barriers positioned in subsequent levels. For other relations across the levels, we suggest the readers review Table A2. In order to increase the connectivity in the model without increasing its complexity, we also connected B11 - B12, B11 - B1, and B12 - B13 even though they are not positioned at the subsequent levels. The model is interpreted by the results of MICMAC analysis with several managerial insights in section 4.2 in details.

Table 6. The barriers at the determined levels through iterations. (Source: Authors own work.)

Level	Barrier	Reachability Set	Antecedent Set
1	B4	B1, B2, B3, B4, B6, B8, B9, B10, B12, B13, B15, B17, B18	B1, B2, B3, B4, B5, B6, B7, B8, B9, B10, B11, B12, B13, B14, B15, B16, B17, B18, B19
1	B13	B1, B2, B3, B4, B5, B6, B8, B9, B10, B13, B14, B15, B17, B18	B1, B2, B3, B4, B5, B6, B7, B8, B9, B10, B11, B12, B13, B14, B15, B16, B17, B18, B19
1	B15	B4, B5, B8, B13, B14, B15	B1, B2, B3, B4, B5, B6, B7, B8, B9, B10, B11, B12, B13, B14, B15, B16, B17, B18, B19
2	B9	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11, B12, B14, B17, B18	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11, B12, B14, B16, B17, B18, B19
2	B10	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11, B12, B14, B17, B18	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11, B12, B14, B16, B17, B18, B19
2	B17	B3, B9, B10, B17, B18	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11, B12, B14, B16, B17, B18, B19
2	B18	B1, B2, B5, B6, B8, B9, B10, B12, B16, B17, B18, B19	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11, B12, B14, B16, B17, B18, B19
3	B2	B1, B2, B3, B5, B6, B7, B8, B12, B16, B19	B1, B2, B3, B5, B6, B7, B8, B11, B12, B14, B16, B19
3	B3	B1, B2, B3, B5, B6, B8, B12, B14, B16	B1, B2, B3, B5, B6, B7, B8, B11, B12, B14, B16, B19
3	B5	B1, B2, B3, B5, B6, B8, B12, B16	B1, B2, B3, B5, B6, B7, B8, B11, B12, B14, B16, B19
3	B8	B1, B2, B3, B5, B6, B7, B8, B12, B14, B16	B1, B2, B3, B5, B6, B7, B8, B11, B12, B14, B16, B19
3	B12	B2, B3, B5, B8, B11, B12, B14	B1, B2, B3, B5, B6, B7, B8, B11, B12, B14, B16, B19
4	B1	B1, B6, B14	B1, B6, B7, B11, B14, B16, B19
4	B6	B1, B6, B7, B16	B1, B6, B7, B11, B14, B16, B19
5	B16	B16, B19	B7, B14, B16, B19
5	B19	B16, B19	B7, B16, B19
6	B7	B7	B7, B14
7	B14	B14	B11, B14
8	B11	B11	B11

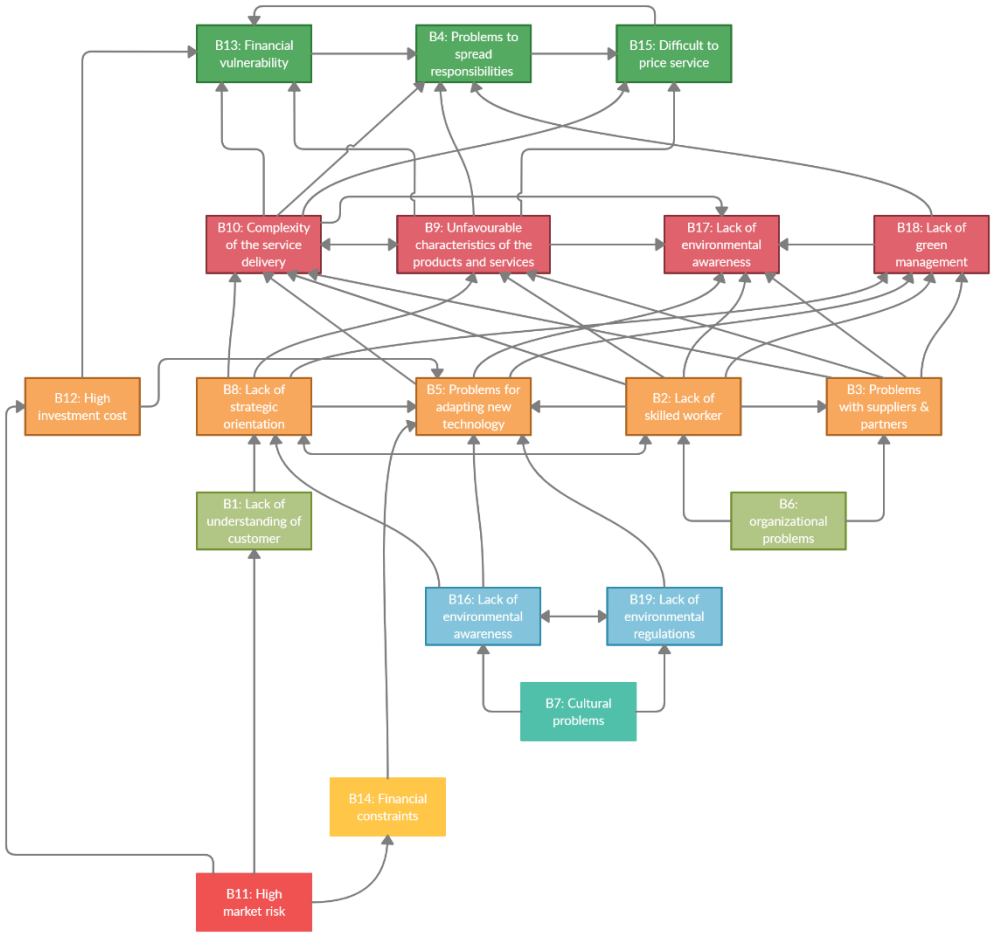

Figure 3. Fuzzy-TISM digraph of sustainable servitization barriers. (Source: Authors own work.)

4.1. The Practical Implications

Practical implications in this study are presented based on the numerical implementation given in the previous section. As mentioned in section 3.1.5, the barriers are differentiated into four categories according to their dependence and driving powers using Fuzzy-MICMAC analysis. We implemented the four steps of the analysis as described in section 3.1.5 using fuzzy evaluations in Table A3. The resulting fuzzy dependence and driving powers and their corresponding crisp values are demonstrated in Table A3. Thus, the barriers are clustered as seen in Figure 4 and the following characteristics were identified.

- There are no autonomous barriers in our analysis. This provides a strong argument that all of the identified barriers have significant effect on servitization. This shows that each barrier identified in this study reflects a real situation that both managers and practitioners would face in a real industry & service applications.
- The second quadrant (Q2) clusters the dependent barriers. These barriers are "Problems to spread responsibilities (B4)", "Problems for adapting new technology (B5)", Difficult to price service (B15)" and "Problems in green service (B17)." These barriers are

strongly affected by the other barriers and they have weak driving powers, especially the barriers B15 and B17. Due to their dependency, these barriers are located at the upper levels of the TISM digraph (see Figure 3). Especially in the case of "Problems for adapting new technology", people should definitely be supported with training in practical application. Again, there should be clear statements in practical application to determine who is the main interlocutor in solving problems that arise with the use of technology. The authorities and responsibilities of people should be written clearly.

- It is not surprising to see that many of the barriers are linkage barriers because of their significant effect on other barriers and their dependency on others. The third quadrant (Q3) in Figure 4 groups of the linkage barriers. As expected, these barriers are usually located at the mediatory levels in the hierarchical TISM digraph (see Figure 3). These are also accounted as critical barriers to the success of servitization because of their connectivity.
- The last category, the fourth quadrant (Q4), shows the independent barriers. As seen in Figure 3, they are "Lack of understanding of customer (B1)", "Cultural problems (B7)", "High market risk (B11)", "Financial constraints (B14)", "Lack of environmental awareness (B16)" and "Lack of environmental regulations (B19)." They are considered very critical elements due to their strong driving powers. These barriers are usually located at the bottom of the hierarchical TISM digraph. For instance, the barrier B11 is a very significant and critical barrier due to its very strong driving power. Because of this, it forms the base of the hierarchical TISM digraph that implicitly suggests being resolved at the beginning of the success of servitization. Although these criteria seem independent, in fact, they constitute the basic elements of servitization, each of which is interconnected within itself.

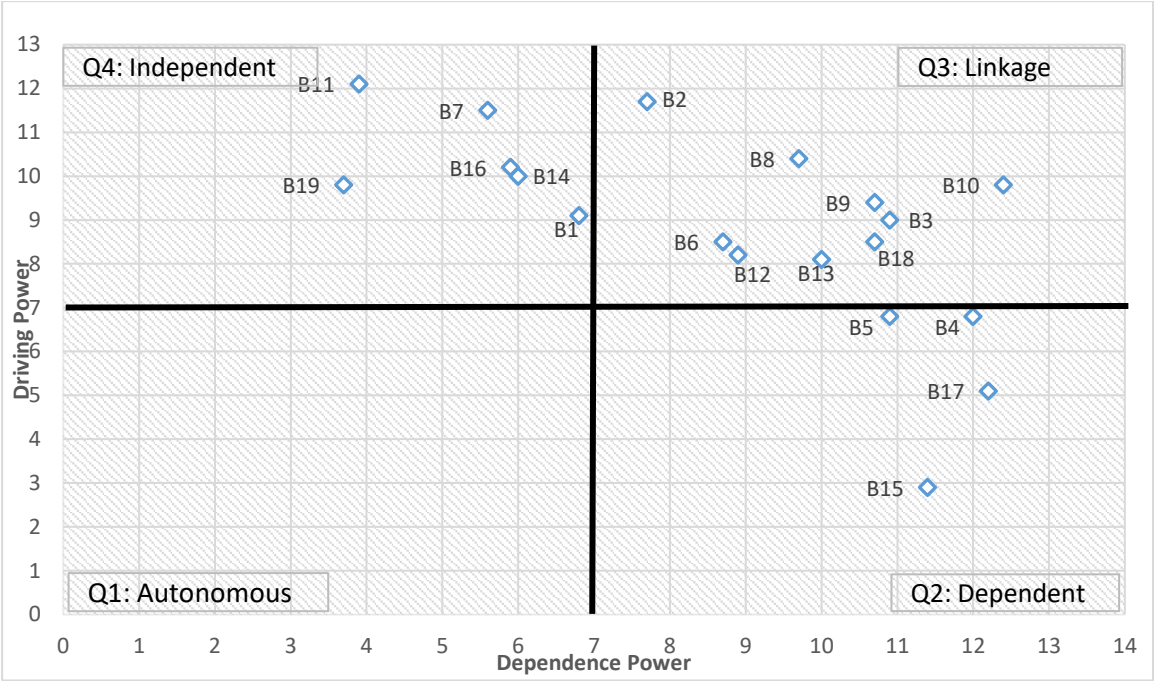

Figure 4. The barriers' clusters identified by Fuzzy-MICMAC analysis. (Source: Authors own work.)

4.2. Managerial Implications

The hierarchical digraph demonstrated (Figure 3) and the identified clusters (Figure 4) of the sustainable servitization barriers present valuable insights about the barriers' characteristics and their significant relationship. Hence, these findings could help decision-makers in developing a better strategy map for implementing a sustainable servitization. The following suggestions are only some of the insights that could be developed from the graphs.

- High market risk (B11) is acting as an independent and a key barrier and required to be carefully analyzed before initiating the servitization strategy because it significantly affects financial constraints (B14), investment cost (B12), and even customer behaviors (B1). Hence, we can suggest that the managers should first make sure about the uncertainties and the movements in the market such as the risk of inflation, exchange rate, and competition level.
- The bottom level barriers such as financial constraints (B14) and cultural problems (B7) are independent and dominant barriers and need to be resolved beforehand for the successful adoption of sustainable servitization. Because cultural problems usually take a long time to be resolved, we suggest managers develop an immediate education and training programs for increasing environmental awareness of their partners such as

suppliers, workers, and even customers. They should also be keen insisting on promoting environmental perspective within and across the organization for building a culture and even playing a role in developing regulations.

- While carefully considering the long-term barriers abovementioned, the managers should simultaneously work on organizational problems (B6) such as structure, hierarchy, collaboration, etc. to enhance its capabilities such as agility, flexibility, speed, and innovation.
- After resolving many of the external, cultural, financial, and organizational barriers, the managers should be interested in finding skilled workers (B2) and adopting new technologies (B5) in line with companies' developed strategies (B8). Simultaneously, the managers should work with their suppliers and partners (B3) and decide how much they will invest (B12) for the new business model. Because these barriers are connected to many other barriers, especially at the top levels, they should be resolved in a short period of time.
- The success of enabling sixth level barriers will help to achieve the seventh level barriers due to their significant dependency. Hence, the strategy, technology, investment budget, the skill of workers and relations with partners will affect designing the characteristics of the products and services, how they will be delivered, green management and service during production and delivery.
- Last but not the least, the manager should successfully maintain their cash flows and monitor the appropriate financial metrics (B13), determine their pricing strategies (B15), and decide how the responsibilities are shared (B4) between customers and suppliers. Because of their strong dependencies, the level of success in the bottom level barriers will significantly affect their achievement.

In the overall evaluation of the results of the study, the findings presented that lack of understanding of customer, cultural problems, high market risk, financial constraints, lack of environmental awareness, and lack of environmental regulations are independent variables and play a very critical role in the success of sustainable-servitization implementations. So, managers and policy makers can be used as a guide to develop a better strategy for their implementations.

5. Conclusion

Servitization is spreading rapidly, offering an important economic opportunity, especially for manufacturing companies. It appears that this new business model can help companies meet their environmental and social needs, as well as their ability to generate competitive benefits. However, besides its advantages, it is not that easy to adopt and implement servitization. It is especially important to identify the barriers and difficulties in front of sustainable servitization and to take measures. However, studies that examine the barriers to servitization in terms of sustainability are lacking in the literature.

Therefore, this study aimed to answer three research questions: First, it determined the main barriers and challenges for sustainability-oriented servitization. Then, the relationship between servitization and sustainability dimensions were highlighted. Second, Fuzzy-TISM method was used to analyze the causal relationships between servitization and human, business, economic and market, and environmental dimensions. Hence, we provided significant relationships among the barriers and their importance for the implementations. Third, we proposed a structured hierarchical model for helping decision-makers to develop a better sustainable-servitization strategy. Thus, this study contributes to both industry and academia with novelty to integrate sustainability dimensions with servitization and the proposed structured map of barriers. Several managerial implications were also suggested for practitioners. As a results, regular meetings between policymakers and sector representatives should be organized for continuous improvement and tracing changes in regulations to remain up to date.

The findings of this study are bounded with the identified barriers and the selected experts' thoughts. We considered nineteen barriers in this study of which the majority were extracted from the previous studies and some were added by our experts. Their significance was also confirmed by the selected experts in consensus. Moreover, the findings that were obtained using Fuzzy-TISM also rely on the experts' thoughts. Because of the qualitative aspects of the decision-making process, it may be possible to see some variations when the number of experts is changed. Therefore, our findings may lead researchers to focus on specific industries such as supply chain, logistics, and warehousing to obtained deeper insights. Hence, in future studies, researchers may focus on industry-specific sustainable servitization barriers and study with a group of expert's from that specific industry.

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Appendix

Table A1. Aggregated Fuzzy-Structural Self-Interaction Matrix. (Source: Authors own work.)

#	Barriers	B19	B18	B17	B16	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2
B1	lack of understanding of customer	NO	V(L)	X(H,VL)	A(L)	X(VH,L)	V(L)	V(H)	NO	A(H)	X(VH,L)	X(H,L)	X(H,L)	A(L)	V(VL)	V(L)	X(H,H)	V(L)	A(L)
B2	lack of skilled worker	NO	V(H)	V(H)	X(L,VL)	V(H)	X(VL,H)	X(L,L)	X(L,L)	A(VL)	X(VH,H)	X(H,H)	X(H,H)	X(H,H)	X(H,H)	V(VH)	V(H)	X(H,VL)	
B3	problems with suppliers & partners	A(H)	X(H,L)	X(H,H)	X(L,L)	V(H)	X(VL,L)	X(H,H)	A(L)	A(H)	X(H,L)	X(H,L)	A(L)	A(L)	X(L,H)	X(L,H)	X(H,H)		
B4	problems to spread responsibilities	A(H)	A(H)	V(H)	A(H)	V(VH)	A(H)	X(VL,H)	X(L,L)	A(H)	X(H,H)	A(H)	A(L)	A(H)	X(L,H)	A(L)			
B5	problems for adapting new technology	A(H)	V(H)	V(H)	A(H)	V(L)	A(VH)	X(VL,L)	X(L,VH)	A(H)	X(H,L)	X(L,H)	A(H)	A(H)	A(L)				
B6	organizational problems	A(L)	X(H,VL)	V(L)	A(L)	V(VL)	A(L)	X(L,L)	X(L,L)	A(L)	X(H,H)	V(VL)	X(L,H)	X(L,H)					
B7	cultural problems	X(H,VL)	X(H,L)	X(H,VL)	X(H,L)	V(L)	A(VL)	V(VL)	V(L)	X(L,L)	V(H)	V(L)	X(H,L)						
B8	lack of strategic orientation	A(L)	X(H,H)	V(L)	X(L,H)	V(L)	X(L,H)	X(H,H)	X(VL,L)	A(H)	X(H,L)	X(H,L)							
B9	unfavorable characteristics of the products and services	A(H)	X(L,H)	X(H,L)	A(H)	V(H)	A(H)	V(H)	X(H,L)	A(L)	X(VH,VH)								
B10	complexity of the service delivery	A(H)	A(H)	X(H,L)	A(H)	V(VH)	X(VL,VH)	V(H)	V(H)	A(L)									
B11	high market risk	X(L,L)	V(L)	A(L)	V(L)	V(H)	X(H,L)	V(VH)	X(VH,H)										
B12	high investment cost	A(L)	X(VL,L)	A(L)	NO	V(L)	V(VH)	X(VH,L)											
B13	financial vulnerability	NO	X(L,VL)	V(L)	NO	X(L,H)	X(VH,L)												
B14	financial constraints	NO	V(H)	V(H)	NO	V(VL)													
B15	difficult to price service	A(L)	A(L)	A(VL)	A(L)														
B16	lack of environmental awareness	X(H,H)	X(VH,H)	V(VH)															
B17	problems in green service	A(H)	X(L,VH)																
B18	lack of green management	A(H)																	

Table A2. The aggregated Fuzzy-Reachability Matrix with linguistic variables. (Source: Authors own work.)

#	Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19
B1	lack of understanding of customer	VH	NO	L	H	L	VL	NO	H	H	VH	NO	NO	H	L	VH	NO	H	L	NO
B2	lack of skilled worker	L	VH	H	H	VH	H	H	H	H	VH	NO	L	L	VL	H	L	H	H	NO
B3	problems with suppliers & partners	NO	VL	VH	H	L	L	NO	NO	H	H	NO	L	H	VL	H	L	H	H	NO
B4	problems to spread responsibilities	H	NO	H	VH	NO	L	NO	NO	NO	H	NO	L	VL	NO	VH	NO	H	NO	NO
B5	problems for adapting new technology	NO	NO	H	L	VH	NO	NO	NO	L	H	NO	L	VL	NO	L	NO	H	H	NO
B6	organizational problems	NO	H	H	H	L	VH	L	L	VL	H	NO	L	L	NO	VL	NO	L	H	NO
B7	cultural problems	L	H	L	H	H	H	VH	H	L	H	L	L	VL	NO	L	H	H	H	H
B8	lack of strategic orientation	L	H	L	L	H	H	L	VH	H	H	NO	VL	H	L	L	L	L	H	NO
B9	unfavorable characteristics of the products and services	L	H	L	H	H	NO	NO	L	VH	VH	NO	H	H	NO	H	NO	H	L	NO
B10	complexity of the service delivery	L	H	L	H	L	H	NO	L	VH	VH	NO	H	H	VL	VH	NO	H	NO	NO
B11	high market risk	H	VL	H	H	H	L	L	H	L	L	VH	VH	VH	H	H	L	L	L	L
B12	high investment cost	NO	L	NO	L	VH	L	NO	L	L	NO	H	VH	VH	VH	L	NO	NO	VL	NO
B13	financial vulnerability	NO	L	H	H	L	L	NO	H	NO	NO	NO	L	VH	VH	L	NO	L	L	NO
B14	financial constraints	NO	H	L	H	VH	L	VL	H	H	VH	L	NO	L	VH	VL	NO	H	H	NO
B15	difficult to price service	L	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	H	NO	VH	NO	NO	NO	NO
B16	lack of environmental awareness	L	VL	L	H	H	L	L	H	H	H	NO	NO	NO	NO	L	VH	VH	VH	H
B17	problems in green service	VL	NO	H	NO	NO	NO	VL	NO	L	L	NO	L	NO	NO	VL	NO	VH	L	NO
B18	lack of green management	NO	NO	L	H	NO	VL	L	H	H	H	NO	L	VL	NO	L	H	VH	VH	NO
B19	lack of environmental regulations	NO	NO	H	H	H	L	VL	L	H	H	L	L	NO	NO	L	H	H	H	VH

Table A3. The corresponding aggregated Fuzzy-Reachability Matrix with fuzzy numbers (Part 1) (Source: Authors own work.)

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
B1	(0.75,1,1)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0,0,0.25)
B2	(0.25,0.5,0.75)	(0.75,1,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0,0,0.25)
B3	(0,0,0.25)	(0,0.25,0.5)	(0.75,1,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)
B4	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)	(0.75,1,1)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)
B5	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.75,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0,0.25)
B6	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)	(0,0,0.25)
B7	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)
B8	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.75,1,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)
B9	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)
B10	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0,0.25)	(0.25,0.5,0.75)	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)
B11	(0.5,0.75,1)	(0,0.25,0.5)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1,1)
B12	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(0.5,0.75,1)
B13	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)
B14	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)
B15	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)
B16	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)
B17	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0.25,0.5)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)
B18	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)
B19	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)
Fuzzy DepP.	(3.5,6.25,10.75)	(4.25,7.25,11.75)	(6.75,11,15.5)	(8,12.25,16.75)	(7.25,11,14.75)	(4.75,8.5,13)	(2.5,5,9.5)	(6,9.5,14)	(6.75,10.75,15)	(8.75,12.75,16.25)	(2,3.25,7.75)
Crisp DepP.	6.8	7.7	10.9	12.0	10.9	8.7	5.6	9.7	10.7	12.4	3.9

Table A3. The corresponding aggregated Fuzzy-Reachability Matrix with fuzzy numbers (Part 2) (Source: Authors own work.)

Barriers	B12	B13	B14	B15	B16	B17	B18	B19	*Fuzzy DrP.	*Crisp DrP.
B1	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.75,1,1)	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0,0.25)	(5.75,9,13)	9.1
B2	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(7.75,12,16)	11.7
B3	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(5.25,8.75,13.25)	9.0
B4	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.75,1,1)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(4,6.25,10.5)	6.8
B5	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(3.75,6.25,10.75)	6.8
B6	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0.25,0.5)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0,0.25)	(4.75,8.25,12.75)	8.5
B7	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(7.25,11.75,16.25)	11.5
B8	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0,0.25)	(6.25,10.5,15)	10.4
B9	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0,0.25)	(6,9.25,13.5)	9.4
B10	(0.5,0.75,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0.75,1,1)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(6.25,9.75,13.75)	9.8
B11	(0.75,1,1)	(0.75,1,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(7.75,12.5,16.5)	12.1
B12	(0.75,1,1)	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0,0.25,0.5)	(0,0,0.25)	(5,8,11.75)	8.2
B13	(0.25,0.5,0.75)	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(4.75,7.75,12)	8.1
B14	(0,0,0.25)	(0.25,0.5,0.75)	(0.75,1,1)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(6.25,10,14)	10.0
B15	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0.75,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1.5,2.25,6.75)	2.9
B16	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.75,1,1)	(0.75,1,1)	(0.75,1,1)	(0.5,0.75,1)	(6.5,10.25,14.25)	10.2
B17	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0,0.25,0.5)	(0,0,0.25)	(0.75,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(2.25,4.5,9)	5.1
B18	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)	(5,8.25,12.5)	8.5
B19	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(6,9.75,14.25)	9.8
***Fuzzy DP.**	(5,8.75,13)	(6,10,14)	(3.25,5.5,9.5)	(7,11.75,15.5)	(3.25,5.25,9.75)	(8.25,12.5,16.5)	(6.75,10.75,15)	(2,3,7.5)		
***Crisp DP.**	8.9	10.0	6.0	11.4	5.9	12.2	10.7	3.7		

*DP. and DrP. Stand for Dependence and Driving Powers, respectively.

Table A4. Defuzzified Reachability Matrix with Full transitivity. (Source: Authors own work.)

#	Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	Driving Power
B1	lack of understanding of customer	1	1*	1*	1	1*	1*	0	1	1	1	0	1*	1	1*	1	0	1	1*	0	15
B2	lack of skilled worker	1*	1	1	1	1	1	1	1	1	1	0	1*	1*	0	1	1*	1	1	1*	17
B3	problems with suppliers & partners	1*	1*	1	1	1*	1*	0	1*	1	1	0	1*	1	1*	1	1*	1	1	0	16
B4	problems to spread responsibilities	1	1*	1	1	0	1*	0	1*	1*	1	0	1*	1*	0	1	0	1	1*	0	13
B5	problems for adapting new technology	1*	1*	1	1*	1	1*	0	1*	1*	1	0	1*	1*	0	1*	1*	1	1	0	15
B6	organizational problems	1*	1	1	1	1*	1	1*	1*	1*	1	0	1*	1*	0	1*	1*	1*	1	0	16
B7	cultural problems	1*	1	1*	1	1	1	1	1	1*	1	0	1*	1*	0	1*	1	1	1	1	17
B8	lack of strategic orientation	1*	1	1*	1*	1	1	1*	1	1	1	0	1*	1	1*	1*	1*	1*	1	0	17
B9	unfavorable characteristics of the products and services	1*	1	1*	1	1	1*	1*	1*	1	1	1*	1	1	1*	1	0	1	1*	0	17
B10	complexity of the service delivery	1*	1	1*	1	1*	1	1*	1*	1	1	1*	1	1	1*	1	0	1	1*	0	17
B11	high market risk	1	1*	1	1	1	1*	0	1	1*	1*	1	1	1	1	1	0	1*	1*	0	16
B12	high investment cost	0	1*	1*	1*	1	0	0	1*	1*	1*	1	1	1	1	1*	0	1*	1*	0	14
B13	financial vulnerability	1*	1*	1	1	1*	1*	0	1	1*	1*	0	0	1	1	1*	0	1*	1*	0	14
B14	financial constraints	1*	1	1*	1	1	1*	1*	1	1	1	0	1*	1*	1	1*	1*	1	1	0	17
B15	difficult to price service	0	0	1*	1*	0	0	0	1*	0	0	0	0	1	1*	1	0	0	0	0	6
B16	lack of environmental awareness	1*	1*	1*	1	1	1*	0	1	1	1	0	1*	1*	0	1*	1	1	1	1	16
B17	problems in green service	0	0	1	1*	0	0	0	0	1*	1*	0	0	1*	0	1*	0	1	1*	0	8
B18	lack of green management	1*	1*	0	1	1*	1*	0	1	1	1	0	1*	1*	0	1*	1	1	1	1*	15
B19	lack of environmental regulations	1*	1*	1	1	1	1*	0	1*	1	1	0	1*	1*	0	1*	1	1	1	1	16
	Dependence Power	16	17	18	19	16	16	7	18	18	18	4	16	19	10	19	10	18	18	5	