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Modelling of green manufacturing barriers using a survey-integrated decision-making approach

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ABSTRACT

Green manufacturing (GM) barriers encompass challenges and obstacles that impede the seamless adoption and effective implementation of environmentally sustainable practices within the manufacturing industry. This paper is dedicated to identifying, analyzing, ranking, and modeling the primary barriers that hinder the integration of GM practices. The study meticulously identifies 11 barriers through an extensive literature review and expert opinions. These barriers are subsequently validated by gathering insights from 90 survey responses. To evaluate these challenges, the study employs a survey-based integrated decision-making model that synergizes Fuzzy Analytic Hierarchy Process (FAHP), Interpretive Structural Modeling (ISM), and Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) methods. This model not only ranks the identified barriers but also delves into their intricate interrelationships. A sensitivity analysis is conducted to fortify the dependability of the findings. Among these obstacles, two stand out as the most prominent including “lack of research and development facilities” and “insufficient in-house knowledge on environmental issues”. This research represents a pioneering endeavor in its domain, shedding light on the vital realm of green manufacturing and its associated challenges.

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1. Introduction

Since the industrial revolution, technical breakthroughs have fuelled innovation and productivity in the manufacturing business (Sharma & Gidwani, 2021). The rapid increase of manufacturing activity over the last few decades has caused havoc on our ecosystem due to the uncontrolled use of natural resources (Pathak et al., 2021). Environmental degradation, resource depletion, and population expansion are all important issues confronting the world today, posing serious threats to human existence and development (Lin & Hao, 2020). Environmental degradation and deterioration have become a major source of concern in recent years in many regions of the world, particularly emerging countries (Asif et al., 2020).

Green Manufacturing (GM) is a production method that avoids pollution, waste, and other adverse environmental effects while conserving natural resources (Gandhi et al., 2018; Almansoori, 2021; Zhu et al., 2023). Businesses can increase their energy efficiency, water conservation, and recycling performance by introducing GM practises into their operations (Yong et al., 2019). Numerous researches have confirmed the benefits of GM, including the following: Abdullah et al., 2015; Belekar, 2017; and Mendoza-fong et al., 2019; D'Angelo et al., 2023.

Ethiopia's manufacturing sector has grown at a phenomenal rate over the previous decade, and the country has declared an aspiration to become Africa's largest manufacturing powerhouse (National Planning

Commission 2016:82). Ethiopia is pursuing the goal of becoming Africa's manufacturing hub and has made significant strides in attracting foreign direct investment. The country operates a small number of industrial parks that are home to a diverse spectrum of manufacturers from China, Europe, and North America. Over the last two decades, Ethiopia's manufacturing output has increased by 17.9 percent (Oqubay 2018). Additionally, Ethiopia has set a goal of developing a climate-resilient green economy by 2025. (New business Ethiopia news, & Behak, 2021, June 24). With the support of international development partners, nations such as Rwanda, Ethiopia, and Mauritius have outlined ambitious plans to dissociate industrialisation from environmental concerns and accelerate the transition to green economies (Wakeford et al., 2017). Even though Ethiopia's green economy goals consider the potential challenges related to green development and green production, only a few studies have been undertaken to determine the elements and barriers that influence the adoption of GM in the manufacturing sector (Andaregie & Astatkie, 2021). Manufacturing firms in developing countries such as Ethiopia are still working out how to include GM into their business operations (Beyene, 2015).

A number of barriers have influenced the adoption of GM by small and large businesses (Mittal et al., 2013; Kumar & Singh, 2014; Niemann, 2016; Wang et al., 2023). Numerous studies of the literature have emphasised the critical nature of establishing the barriers for GM. Yet, because industrial and environmental regulations vary among countries, the barriers for GM may also vary (Tumaini, 2021). While Ethiopia's green economy initiatives consider potential impediments to green development in general and green production in particular, only a few studies have been undertaken to establish the barriers impacting the adoption of GM in the industrial sector (Andaregie & Astatkie, 2021). No study was conducted to determine the extent to which company-specific characteristics influence GM adoption. As a result, manufacturing sectors in developing countries such as Ethiopia are still figuring out how to incorporate GM into their business operations (Beyene, 2015). A detailed study of the barriers to GM adoption is required to comprehend the ground realities of the same in Ethiopia's manufacturing sector.

Thus, the goal of this study was to identify, analyse, and model the barriers to GM adoption for an Ethiopian manufacturing firm. This is the first study to analyse and model the barriers to GM implementation in Ethiopian manufacturing sector employing an integrated survey-based Fuzzy Analytic Hierarchy Process (FAHP), Interpretive Structural Modeling (ISM), and Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) approach.

1.1. Research Objectives

This study aimed to address the following research objectives for the manufacturing industry in Ethiopia:
Research Objective 1. Determining the barriers to GM
Research Objective 2. Prioritizing and modelling the barriers to GM
The remainder of the paper is divided into the following sections: The next section summarises the available literature. This will be followed by a description of the methods used to analyse the data, and then the findings of the analysis will be detailed. The next section analyses the study's significance. The concluding part summarises the findings of the research and makes recommendations for future research.

2. Literature

As standards grew, numerous corporations, particularly in the United Kingdom, began implementing environmental policies in the early 1990s. Environmentally conscientious manufacturing, clean manufacturing, environmentally friendly production, environmentally responsible production, and clean manufacturing are all terms that have been used to describe GM in various studies (Sangwan & Mittal, 2015). GM enables the production of economically viable commodities by mitigating social and environmental consequences (Thanki et al., 2016). GM is also defined as a collection of initiatives, activities, and approaches that have the ability to improve economic, environmental, and social quality, as well as contribute to the reduction of the impact of business operations on the triple bottom line (Alayón et al., 2017). GM is important to ensure the product's creation is non-hazardous and safe, with the least possible impact through the use of the best resources (Rehman et al., 2016).

Although the concept of GM extends all the way back to the 1990's (Sezen and Cankaya, 2013), it has attracted significant research interest over the last two decades as a result of demand from a variety of stakeholders concerned with sustainability challenges (Bai et al., 2015; Rehman et al., 2016). Nimawat and Namdev (2012) defined GM as the application of efficient manufacturing processes and equipment with the goal of decreasing waste and improving productivity. Additionally, GM is regarded as an extremely efficient manufacturing technology and industrial process because it utilises inputs that produce little or no pollution and minimise waste, thus reducing the negative ecological impact (Ghazilla et al., 2015). Thus, the primary objective of GM adoption is to secure the sustainability of industrial output.

To enable the successful adoption of GM, critical factors should be understood as existing or developing circumstances or practises (Ninlawan et al. 2010). Numerous research identified various parameters indicating potential directions for a GM system. Sarkis and Rasheed (1995) proposed four criteria (reduce, recycle, remanufacture, and re-use) to account for the green characteristics of the manufacturing process. Variables such as GM procedures, operational capital, technological ingenuity, and programme control all play a vital impact in the deployment of environmental technology (Gunasekaran and Spalanzani, 2012). Lun (2011) examined the components of GM practises and their effect on company performance.

By doing a literature review, Jabbour (2013) identified future prospects for providing environmental training for businesses in order to improve and promote GM practises within the firm. Zeng et al. (2014) conducted a theoretical examination of the requirements of Chinese firms pursuing green innovation strategies. They discovered that money, suppliers, regulators, competition, and customers all exert significant pressure on green technologies. According to several research, businesses are successfully integrating GM strategies in order to increase profitability and organisational performance (Roy and Khastagir 2016). Additionally, research examined factors affecting green growth in various countries and sectors, including India (Mittal and Sangwan, 2015; Govindan et al., 2015; Sharma et al., 2021), the United States of America (Yi H, 2014), Turkey (Agan et al., 2013), Spain (Santolaria et al., 2011), and Bangladesh (Moktadir et al . , 2018). Micheli et al. (2020) discovered that some drivers have a significant influence on the interaction between drivers and practises, as well as on the relationship between practises and performance, in Italian manufacturing enterprises. GM practises compliance in Indian small and medium-sized enterprises (SMEs) are hindered by a lack of research and development, an absence of eco-design principles, and an absence of accreditation, according to Karuppiah et al. (2020).

In light of the aforementioned literature analysis, and to the best of the author's knowledge, no study exists that analyses and models' the barriers in Ethiopia's manufacturing industries. This study identifies, analyses, and models the barriers to GM implementation for an Ethiopian manufacturing company. Table 1 summarise the barriers identified in the literature.

Table 1. GM Barriers

Green Manufacturing Barriers	Authors
Lack of top management commitment	(Luthra et al., 2011), (Gandhi et al. 2015)
Financial constraints	(Abualfaraa et al., 2020), (Singh et al. 2020)
Complexity of design to reuse/recycle used products	(Menon & Ravi, 2021) (Kaur et. al. 2017)
Lack of pressure from society	(Paula et al., 2014) (Mishra 2015)
Lack of in-house knowledge with environment issues	(Mittal & Sangwan 2014)
Lack of training and awareness programs	(Kushwaha & Talib, 2020)
Inadequacy in government support systems	(Rosen & Kishawy, 2012) (Bengtsson et al. 2018)
Lack of bank loans to support green product	(Li et al. 2018)
Lack of alternative chemicals/raw material input at affordable cost	(Manhart et al. 2019)
Lack of basic infrastructure facility	
Lack of research and development facility	(Li et al. 2018) (Kushwaha & Talib, 2020 (Soderholm, 2020)

3. Methodology

This work presents a unique approach based on Survey-FAHP-ISM-MICMAC for defining, analysing, and modelling barriers that have a major impact on others. The structure for this investigation is depicted in Figure 1, which mainly consists of three steps. After conducting a complete examination of the literature to identify barriers, the list of identified barriers was submitted to eight experts, who were requested to add any missing things from their perspectives. The next stage involves conducting a survey of Ethiopian manufacturing industries. A comprehensive questionnaire was developed and distributed to various companies in Ethiopia after identifying barriers through a review of existing research and expert assistance. Subsequently, the returned questionnaires were analysed, and the most frequently acknowledged barriers by diverse organisations were determined. Finally, the FAHP-ISM-MICMAC technique is used to analyse and model key barriers based on feedback from six experts from various Ethiopian manufacturing industries involved in the GM implementation pathway. A sensitivity analysis is also used to determine the model's robustness.

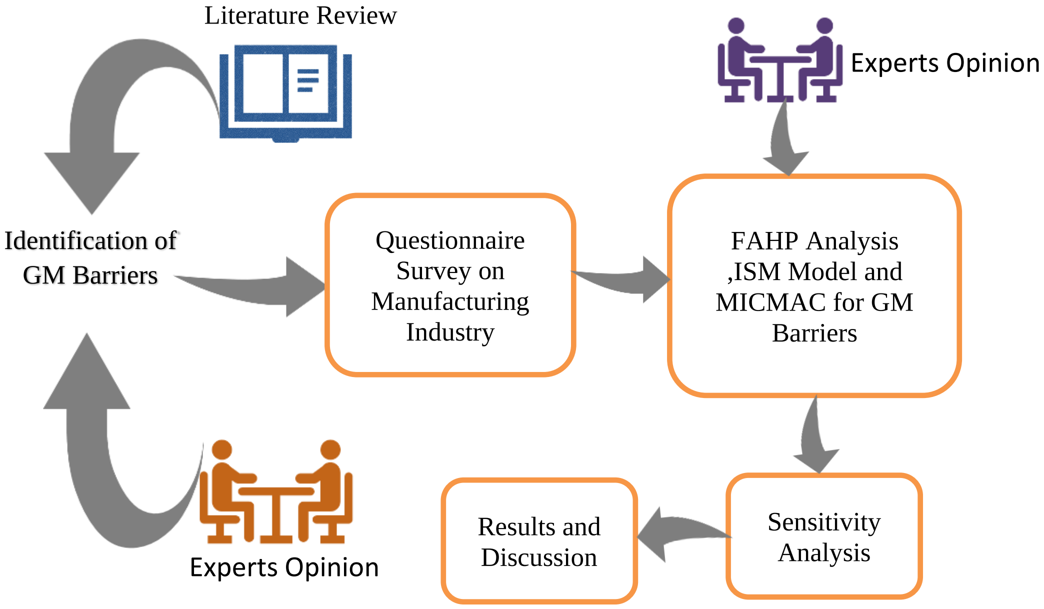

Figure 1. Research Framework

3.1. Profile of experts involved in the study

To acquire realistic results, the researchers aimed to identify qualified experts with domain-specific expertise and experience. Experts were involved in two stages of this study: the first stage involved identifying barriers, and the second stage entailed applying FAHP-ISM-MICMAC methodologies. To achieve this goal, a variety of criteria were used to choose qualifying panels. The following criteria were employed in this study: (1) a bachelor's degree in a relevant field; and (2) at least five years of relevant experience. These two criteria resulted in the selection of eight experts for stage one (identification barriers) and six experts for stage three (FAHP-ISM-MICMAC technique), as indicated in Table 2.

Table 2. Experts Profile

Expert	Education degree	Profile	Experience (Years)	Stage 1	Stage 3
1	UG	Design Engineer	6	✓	--
2	UG	Supervisor	7	✓	--
3	PG	Manager	10	✓	--
4	PG	Env. Expert	8	✓	--
5	PG	Business Owner	10	✓	--
6	UG	Manager	14	✓	--
7	UG	Sr. Manager	13	✓	--
8	PhD	Academic	19	✓	--
9	PhD	Academic	21	--	✓
10	PG	Env. Expert	17	--	✓
11	PG	Manager	15	--	✓
12	UG	Manager	18	--	✓
13	PhD	Academic	17	--	✓
14	UG	CEO	18	--	✓

3.2. Questionnaire Survey

A questionnaire survey was conducted to solicit input from Ethiopia's manufacturing industry after identifying barriers through literature review and expert feedback. The development of the survey questionnaire is commonly recognised as being important to the results' reliability and validity (Creswell, 2009). A questionnaire-based survey was conducted across 90 Ethiopian enterprises to accomplish the purpose. The survey questionnaire was created in accordance with the cited literature and consists mostly of two sections. The first section was used to gather demographic information about the participating businesses, such as their years of operation, their size, and the position of the survey responder. The second section discussed barriers. On a five-point Likert scale, with a minimum rating of 1 and a maximum rating of 5, respondents expressed their opinions. All barriers with a mean value of 2.5 or greater are included in the analysis.

To collect data from the various regions of Ethiopia's manufacturing industry, a random sample of firms from the Ethiopian Industry Directorate was selected. Over 300 industrial companies were randomly selected to receive the final questionnaire. The questionnaire was distributed electronically via the Google Forms platform. Each firm was invited through email and provided with a link to the online questionnaire. Additionally, the e-mail contains a cover page outlining the study's objective, ensuring participant confidentiality and stressing the importance of reviewing the survey results. Additionally, data was gathered through personal visits to selected businesses. Executives, managers, general managers, deputy general managers, chief executives, senior executives, process managers, directors, and design engineers comprised the majority of responders. Respondents were professionals with five to twenty years of work experience.

3.3 FAHP-ISM-MICMAC Method

After confirming barriers in stages 1 and 2, the FAHP-ISM-MICMAC approach was used in the subsequent step of this research. Due to the fact that study objectives 2 entail a variety of barriers, finding a solution will require a holistic approach to decision-making. As a result, the MCDM technique looks to be adequate (Karuppiah et al., 2020). MCDM techniques are extremely successful for analysing, evaluating, and ranking projects that need decision-making (Singh & Agarwal, 2018; Sharma et al., 2021; Sahoo & Goswami, 2023). Numerous MCDM techniques have been created and published in the literature. Each of these methods has distinct characteristics, as well as distinct advantages and disadvantages (Sharma et al., 2022).

The third stage of this project uses a combined Fuzzy AHP-ISM-MICMAC technique to develop an integrated analytical approach for ranking and modelling barriers to GM implementation. Figure 2 depicts the FAHP-ISM-MICMAC steps. The FAHP was used to assign weights to each of the GM barriers and to accurately assess their relative importance. The ISM was used to assess and characterise the links between these barriers intuitively. Finally, a quadrant diagram depicting driving dependence was generated using cross-influence matrix multiplication (MICMAC). Although ISM, AHP, and MICMAC technologies have been utilised for many years, their adaptability and robustness make them extensively applicable in a variety of industries (Jiang et al., 2019). Numerous researchers have recently applied the combined FAHP-ISM-MICMAC technique in a variety of domains (Singh et al., 2018; Gupta & Goyal, 2021; Prabhakar et al., 2021; Bakhtari et al., 2021).

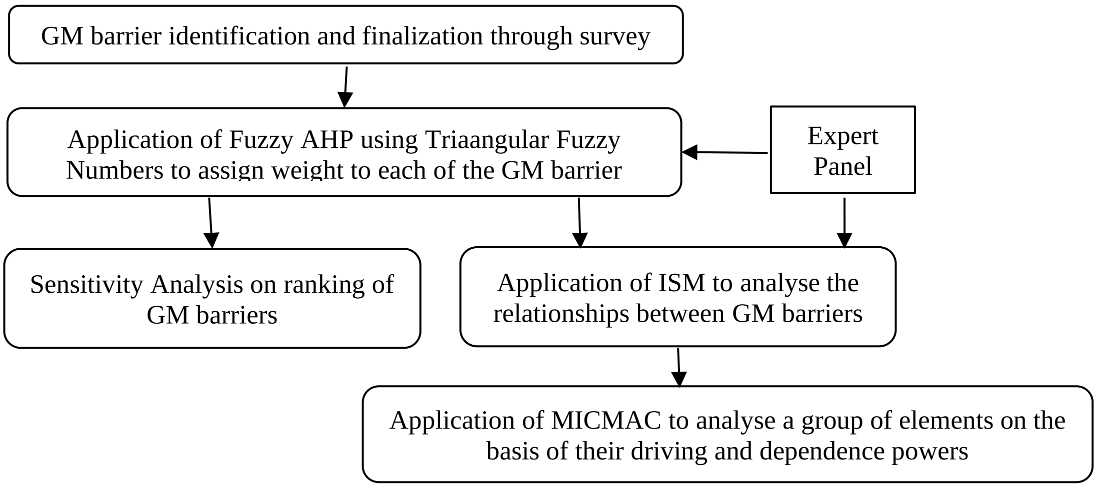

Figure 2. Fuzzy AHP-ISM-MICMAC Framework

3.3.1 Fuzzy AHP (FAHP)

Saaty invented the Analytical Hierarchy Process (1980). This technique persuasively deals with data ambiguity in order to decrease decision-making complications. Human judgments are communicated in linguistic assertions rather than explicit values, and it is here that fuzzy approach can assist in delivering comprehensible information for problem analysis in uncertain environments (Mangla et al. 2015). The fuzzy AHP methodology can be thought of as a more sophisticated version of the classic AHP (Sharma et al., 2021).

The following are the steps involved in fuzzy AHP (Sharma et al., 2021; Nezhad et al., 2023; Nezhad et al., 2023; Younis Al-Zibaree et al., 20023):

Step 1: Determining the objective.

Step 2: Formation of a hierarchical structure.

Step 3: A pairwise comparison.

Triangular fuzzy numbers are used when performing pairwise comparisons. A triangular fuzzy number $\widetilde{A}$ has an associated triplet (a, b, c), which describes the function using the aforementioned equation (1).

$$\mu_{\tilde{A}}(x) denotes = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & x > c \end{cases} \quad (1)$$

Where a, b, and c denote the bottom, mean, and upper values of the triangle fuzzy number, respectively. Experts were asked to make comparisons between all enablers and all barriers using the linguistic terms listed in Table 3. Eq. (2) illustrates the matrix of average pairwise contributions.

$$\begin{bmatrix} \widetilde{d_{11}} & & \widetilde{d_{1n}} \\ . & \cdots & . \\ . & & . \\ \widetilde{d_{n1}} & \cdots & \widetilde{d_{nn}} \end{bmatrix} \quad (2)$$

Step 4: Relative fuzzy weights calculation. Eq. (3) determines the fuzzy weight assigned to each criteria.

$$\widetilde{w_i} = \tilde{r}_i \oplus (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots\ldots\ldots \oplus \tilde{r}_n)^{-1} \quad (3)$$

where

$n \in N$ denotes the total number of criteria

$\tilde{r}_i$ is the geometric mean of the comparison value of criteria *i* to each criteria,

$\widetilde{w_i}$ is the *i*th barrier's fuzzy weight

$\oplus$ is the symbol of matrix plus

Three estimating steps are used to determine the fuzzy weight of the criteria. The first step is to calculate the vector sum of each $\tilde{r}_i$. The second step is to compute the inverse of the summation vector and replace the fuzzy triangular number with increasing order. Finally, the Third Step is to determine the fuzzy weight associated with criteria *i* ($\widetilde{w_i}$), by multiplying each $\tilde{r}_i$ by this reverse vector.

Step 5: *The non-fuzzy weight calculation*. The Centre of area approach is used to defuzzify fuzzy triangular numbers $\widetilde{w_i}$. Refer Eq. (4)

$$M_i = \frac{a\, w_i + b\, w_i + c\, w_i}{3} \quad (4)$$

Step 6: Normalized weight determination. To calculate the normalized weight of any given criteria, use Equation (5).

$$N_i = \frac{Mi}{\sum_{i=1}^{n} Mi} \quad (5)$$

Table 3. Linguistic terms and a fuzzy triangular number (Dağıstanlı, 2023)

Scale	Description	Fuzzy triangular number
1	Equally important	(1, 1, 1)
3	Weakly important	(2, 3, 4)
5	Fairly important	(4, 5, 6)
7	Strongly important	(6, 7, 8)
9	Absolutely important	(9, 9, 9)
2	Intermediate values	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

3.3.2 Interpretive Structural Modeling (ISM)

Warfield invented the ISM technique in 1974 to quantify the interactions between variables in a particular problem. It is a collaborative learning method that is used to express complex interactions between variables in order to improve a system's order and direction (Sage 1977). The ISM model demonstrates the overarching structure of complicated relationships. It is capable of converting perplexed mental constructs into a well-defined visual model (Sharma et al., 2021). The following are the steps involved in ISM:

1. Identifying the relevant variables for the system under investigation.
2. Establishment of the contextual relationships among the variable listed.
3. Creation of a structural self-interaction matrix (SSIM) to depict the interrelationships between variables.
4. Initial reachability matrix is developed using SSIM and then transitivity is checked and the final reachability matrix is created. If factor A has an effect on factor B and factor B has an effect on factor C, then factor A has an indirect effect on factor C.
5. The final reachability matrix (FRM) is partitioned on a level basis.
6. On the basis of FRM, develop a directed graph or digraph.
7. The final stage is to examine the produced ISM-based model for conceptual inconsistencies and then make required revisions.

4. Application of the proposed method and results

4.1 Stage 1

The initial stage of this research was to conduct a complete literature review in order to identify barriers. Following that, as indicated in Table 2, all identified barriers were discussed with eight experts. Finally, eleven barriers were determined to be worthy of further investigation. Table 1 contain a list of all barriers.

4.2 Stage 2

The second stage involved conducting a survey with the primary goal of determining Ethiopian industries' current understanding of GM barriers. A survey of 90 Ethiopian industries was conducted using a questionnaire.

4.2.1 Company profile

Table 4 summarises the profile of the participating companies: the process industry (33.3%), auto component manufacture (26.7%), and machine equipment (21.3%) are the key industries. 15.6% of respondent organisations have fewer than 100 people, another 35.6% have 101–500 employees, 20% have 501–1,000 employees, 24.4% have 1,001–5000 employees, and 4.4% have more than 5,000 employees. Out of 90 responses, 40.34% were from engineering and design, 29.29% were from production management, 13.70% were from corporate or operating management, and 16.67% were head supervisors and quality engineer’s division heads so on.

4.2.2 Survey result

After compiling survey data, the mean value for each barrier was determined. All enablers and barriers with a mean of 2.5 are included in the analysis. Table 5 summarises the average value of all barriers.

4.3 Stage 3

In the third stage of this research a FAHP-ISM-MICMAC method were applied.

4.3.1 Application of FAHP Method

An expert board was formed with the appointment of six professionals. Experts were selected based on their years of experience, managerial abilities, and areas of expertise, such as those listed in Table 2. We employed interactive group discussions to elicit data from experts. Four to ten academic and industrial expertise are required to contribute to the AHP model (Szabo, 2021). The FAHP processes outlined in the methodology section are used to identify barriers. The following steps outline the process.

Step 1: Prioritizing GM implementation barriers is the goal.

Table 4. Company Profile

Item	Percentage	Count
Sector Include		
Automobile Industry	26.7	24
Electrical & Electronics	2.2	2
Machinery	21.3	19
Process Industry	33.3	30
Product Industry	3.3	3
Manufacturing	1.1	1
Automotive Maintenance and Road	1.1	1
Civil Work	2.2	2
Transport Industry	2.2	2
Agriculture	1.1	1
Airlines	2.2	2
Other	3.3	3
Nature of Business		
Privated Limited	46.66	42
Public Limited	48.88	44
Group Limited	4.4	4
Number of Employees		
0-100	15.6	14
101-500	35.6	32
501-1000	20	18
1001-5000	24.4	22
over 5000	4.4	4
Total	100	90

Table 5. Mean value of Barriers

Barrier	Mean
Lack of top management commitment (B1)	2.59
Financial constraints (B2)	2.96
Complexity of design to reuse/recycle used products (B3)	3.03
Lack of pressure from society (B4)	2.58
Lack of in-house knowledge with environment issues (B5)	3.10
Lack of training and awareness programs (B6)	2.78
Inadequacy in government support systems (B7)	2.70
Lack of bank loans to support green product (B8)	2.70
Lack of alternative chemicals/raw material input at affordable cost (B9)	2.89
Lack of basic infrastructure facility (B10)	2.83
Lack of research and development facility (B11)	2.92

Step 2: According to Tables 6, pairwise comparisons of significant barriers are used to estimate the aggregated fuzzy matrix.
Step 3: Tables 7 illustrate the relative fuzzy weights of barriers using Equation (3).
Step 4: Each barrier's relative non-fuzzy weight is measured by Equation (4). Table 7 also shows the normalized weights of each barrier using Eq. (5). Standard weights can be used to determine the barrier's strength.

4.3.2 Sensitivity Analysis

Because the rating is based on human inputs, the ranking's consistency must be confirmed. This can be accomplished through the use of a sensitivity analysis (Prakash & Barua 2016; Sivaprakasam & Angamuthu, 2023). Sensitivity analysis is used to determine the MCDM method's efficacy and the outcome's stability under various settings, including modest alterations in the criteria (Pamuèar & Cirovic, 2015; Pamucar & Biswas, 2023; Jagtap & Karande, 2023). Sensitivity analysis can be performed in a variety of methods, one of which is by exchanging the criteria weights (Nüt et al., 2009; Radovanovic et al., 2023). As a result, this study creates 55 such scenarios in which the weights of two distinct criteria are swapped. Each scenario highlights the weight-exchanging pairings of criteria. Table 8 shows the weights of the barriers for the first ten experimental scenarios, as well as the original scenario. The change in ranking as a result of changes in barrier weights is depicted in Figure 3 for various scenarios.

Table 6. Pairwise comparison matrix for barriers

	B1			B2			B3			B4			B5			B6		
(B1)	1	1	1	0.143	0.167	0.2	0.167	0.2	0.25	1	1	1	0.143	0.167	0.2	0.143	0.167	0.2
(B2)	5	6	7	1	1	1	2	3	4	6	7	8	0.2	0.25	0.334	1	1	1
(B3)	4	5	6	0.25	0.334	0.5	1	1	1	4	5	6	0.167	0.2	0.25	0.143	0.167	0.2
(B4)	1	1	1	0.125	0.143	0.167	0.167	0.2	0.25	1	1	1	0.125	0.143	0.167	0.143	0.167	0.2
(B5)	5	6	7	3	4	5	4	5	6	6	7	8	1	1	1	1	1	1
(B6)	5	6	7	1	1	1	5	6	7	5	6	7	1	1	1	1	1	1
(B7)	1	1	1	0.143	0.167	0.2	0.167	0.2	0.25	2	3	4	0.143	0.167	0.2	0.143	0.167	0.2
(B8)	2	3	4	0.143	0.167	0.2	0.25	0.334	0.5	3	4	5	0.167	0.2	0.25	0.167	0.2	0.25
(B9)	3	4	5	0.2	0.25	0.334	1	1	1	3	4	5	0.167	0.2	0.25	0.167	0.2	0.25
(B10)	4	5	6	1	1	1	1	1	1	5	6	7	0.2	0.25	0.334	0.25	0.334	0.5
(B11)	6	7	8	4	5	6	5	6	7	6	7	8	2	3	4	4	5	6

Table 6. Pairwise comparison matrix for barriers (continue)

	B7			B8			B9			B10			B11		
(B1)	1	1	1	0.25	0.334	0.5	0.2	0.25	0.334	0.167	0.2	0.25	0.125	0.143	0.167
(B2)	5	6	7	5	6	7	3	4	5	1	1	1	0.167	0.2	0.25
(B3)	4	5	6	2	3	4	1	1	1	1	1	1	0.143	0.167	0.2
(B4)	0.25	0.334	0.5	0.2	0.25	0.334	0.2	0.25	0.334	0.143	0.167	0.2	0.125	0.143	0.167
(B5)	5	6	7	4	5	6	4	5	6	3	4	5	0.25	0.334	0.5
(B6)	5	6	7	4	5	6	5	6	7	2	3	4	0.167	0.2	0.25
(B7)	1	1	1	1	1	1	0.25	0.334	0.5	0.143	0.167	0.2	0.125	0.143	0.167
(B8)	1	1	1	1	1	1	1	1	1	0.167	0.2	0.25	0.143	0.167	0.2
(B9)	2	3	4	1	1	1	1	1	1	0.2	0.25	0.334	0.143	0.167	0.2
(B10)	5	6	7	4	5	6	3	4	5	1	1	1	0.167	0.2	0.25
(B11)	6	7	8	5	6	7	5	6	7	4	5	6	1	1	1

4.3.3 Application of the ISM Method

The ISM methodology is used to analyse the relationships between various barriers. Barriers are addressed using the ISM stages outlined in the methodology section. The following steps outline the procedure.

Step 1. SSIM Construction

The expert panel and practitioners in the manufacturing sector examined the interactions between variables in order to construct a structure utilising the self-interaction approach. Because these connections were made in pairs, experts are being asked to establish a contextual relationship between the components. The four symbols (V, A, X, and O) are used to simplify and clarify this process.

Table 7. Fuzzy Weight, Non-fuzzy weight, Normalized weight and Rank of Barriers

Barriers	Fuzzy Weight			Average	Normalized	Rank
Lack of top management commitment (B1)	0.0137	0.0184	0.0258	0.0193	0.0186	10
Financial constraints (B2)	0.0808	0.1114	0.1535	0.1152	0.1111	4
Complexity of design to reuse/recycle used products (B3)	0.0419	0.0580	0.0815	0.0605	0.0583	6
Lack of pressure from society (B4)	0.0114	0.0155	0.0222	0.0163	0.0158	11
Lack of in-house knowledge with environment issues (B5)	0.1270	0.1790	0.2517	0.1859	0.1793	2
Lack of training and awareness programs (B6)	0.1094	0.1496	0.2033	0.1541	0.1486	3
Inadequacy in government support systems (B7)	0.0167	0.0226	0.0317	0.0237	0.0228	9
Lack of bank loans to support green product (B8)	0.0229	0.0317	0.0450	0.0332	0.0320	8
Lack of alternative raw material input at affordable cost (B9)	0.0301	0.0420	0.0596	0.0439	0.0424	7
Lack of basic infrastructure facility (B10)	0.0632	0.0870	0.1220	0.0908	0.0875	5
Lack of research and development facility (B11)	0.2014	0.2848	0.3953	0.2939	0.2834	1

Table 8. Sensitivity analysis scenario for barriers

Barriers	Normalized	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Lack of top management commitment (B1)	0.0186	**0.1111**	**0.0583**	**0.0158**	**0.1793**	**0.1486**	**0.0228**	**0.0320**	**0.0424**	**0.0875**	**0.2834**
Financial constraints (B2)	0.1111	**0.0186**	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
Complexity of design to reuse/recycle used products (B3)	0.0583	0.0583	**0.0186**	0.0583	0.0583	0.0583	0.0583	0.0583	0.0583	0.0583	0.0583
Lack of pressure from society (B4)	0.0158	0.0158	0.0158	**0.0186**	0.0158	0.0158	0.0158	0.0158	0.0158	0.0158	0.0158
Lack of in-house knowledge with environment issues (B5)	0.1793	0.1793	0.1793	0.1793	**0.0186**	0.1793	0.1793	0.1793	0.1793	0.1793	0.1793
Lack of training and awareness programs (B6)	0.1486	0.1486	0.1486	0.1486	0.1486	**0.0186**	0.1486	0.1486	0.1486	0.1486	0.1486
Inadequacy in government support systems (B7)	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	**0.0186**	0.0228	0.0228	0.0228	0.0228
Lack of bank loans to support green product (B8)	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	**0.0186**	0.0320	0.0320	0.0320
Lack of alternative raw material input at affordable cost (B9)	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	**0.0186**	0.0424	0.0424
Lack of basic infrastructure facility (B10)	0.0875	0.0875	0.0875	0.0875	0.0875	0.0875	0.0875	0.0875	0.0875	**0.0186**	0.0875
Lack of research and development facility (B11)	0.2834	0.2834	0.2834	0.2834	0.2834	0.2834	0.2834	0.2834	0.2834	0.2834	**0.0186**

(Note: Due to space limitation, out of 56 scenarios only 10 scenarios are presented in Table 8)

V: The (i) barrier will influence the (j) barrier;
A: The (j) barrier will influence (i) barrier;
X: Both (i and j) barrier will influence each other mutually; and
O: None of the (i and j) barrier will influence each other.
The SSIM for barriers was built using the symbols and expert opinions mentioned in Table 9.

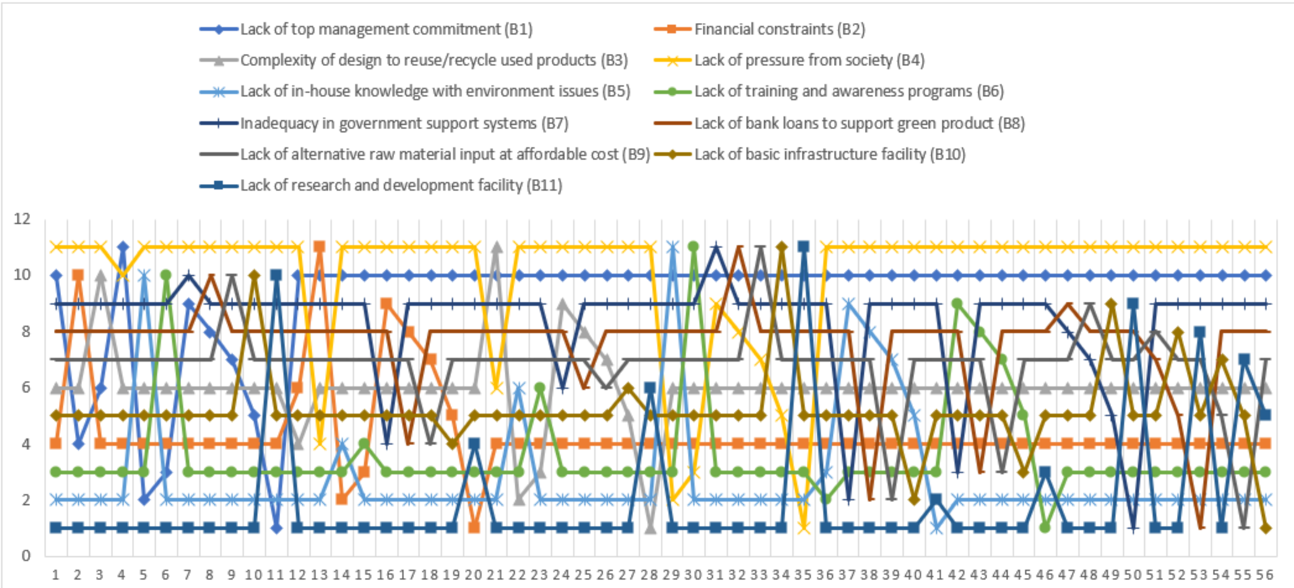

Figure 3. Sensitivity analysis for ranking of barriers

Step 2. Reachability Matrix (IRM) Formation

The SSIM was transformed to binary values for the purpose of creating the reachability matrix. The initial reachability matrix's symbols V, A, X, and O are replaced with 1 and 0 according to the conditions specified below:

For each cell (i,j) containing "V" insert 1 and 0 for (j,i) cell.
For each cell (i,j) containing "A" insert 0 and 1 for (j,i) cell.
For both cells (i,j) and (j,i) containing "X" insert 1.
For both cells (i,j) and (j,i) containing "O" insert 0.

The initial reachability matrix for barriers is shown in Table 10.

Step 3. Final Reachability Matrix Formation

By eliminating transitivity from the IRM, the final reachability matrix was generated using the ISM approach. Table 11 shows the final reachability matrix for barriers (* marks the existence of transitive relationships in the Table). The driving force of a barrier is proportional to the number of barriers it may affect. The dependence power of an barrier is equal to the total number of barriers that could influence it (consisting of themselves).

Table 9. SSIM for Barriers

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
Lack of top management commitment (B1)	*	V	O	O	O	V	O	O	O	V	X
Financial constraints (B2)		*	O	O	X	V	O	X	V	V	V
Complexity of design to reuse/recycle used products (B3)			*	O	X	X	O	O	X	X	A
Lack of pressure from society (B4)				*	X	X	O	O	A	X	X
Lack of in-house knowledge with environment issues (B5)					*	V	O	O	O	O	V
Lack of training and awareness programs (B6)						*	X	X	O	O	A
Inadequacy in government support systems (B7)							*	O	O	O	V
Lack of bank loans to support green product (B8)								*	V	V	V
Lack of alternative raw material input at affordable cost (B9)									*	O	A
Lack of basic infrastructure facility (B10)										*	A
Lack of research and development facility (B11)											*

Table 10. IRM for Barriers

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
Lack of top management commitment (B1)	*	1	0	0	0	1	0	0	0	1	1
Financial constraints (B2)	0	*	0	0	1	1	0	1	1	1	1
Complexity of design to reuse/recycle used products (B3)	0	0	*	0	1	1	0	0	1	1	0
Lack of pressure from society (B4)	0	0	0	*	1	1	0	0	0	1	1
Lack of in-house knowledge with environment issues (B5)	0	1	1	1	*	1	0	0	0	0	1
Lack of training and awareness programs (B6)	0	0	1	1	0	*	1	1	0	0	0
Inadequacy in government support systems (B7)	0	0	0	0	0	1	*	0	0	0	1
Lack of bank loans to support green product (B8)	0	1	0	0	0	1	0	*	1	1	1
Lack of alternative raw material input at affordable cost (B9)	0	0	1	1	0	0	0	0	*	0	0
Lack of basic infrastructure facility (B10)	0	0	1	1	0	0	0	0	0	*	0
Lack of research and development facility (B11)	1	0	1	1	0	1	0	0	1	1	*

Table 11. Final Reachability Matrix for Barriers

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	Driving Power
Lack of top management commitment (B1)	1	1	1*	1*	1*	1	1*	1*	0	1	1	10
Financial constraints (B2)	1*	1	1*	1*	1	1	1*	1	1	1	1	11
Complexity of design to reuse/recycle used products (B3)	0	1*	1	1*	1	1	1*	1*	1	1	1*	10
Lack of pressure from society (B4)	1*	1*	1*	1	1	1	1*	1*	1*	1	1	11
Lack of in-house knowledge with environment issues (B5)	1*	1	1	1	1	1	1*	1*	1*	1*	1	11
Lack of training and awareness programs (B6)	0	1*	1	1	1*	1	1	1	1*	1*	1*	10
Inadequacy in government support systems (B7)	1*	0	1*	1*	0	1	1	1*	1*	1*	1	9
Lack of bank loans to support green product (B8)	1*	1	1*	1*	1*	1	1*	1	1	1	1	11
Lack of alternative raw material input at affordable cost (B9)	0	0	1	1	1*	1*	0	0	1	1*	1*	7
Lack of basic infrastructure facility (B10)	0	0	1	1	1*	1*	0	0	1*	1	1*	7
Lack of research and development facility (B11)	1	1*	1	1	1*	1	1*	1*	1	1	1	11
Driven Power	7	8	11	11	10	11	9	9	10	11	11	

Step 4. Level Partitions

Following the completion of the final reachability matrix process, the reachability, intersection, and antecedent sets must be prepared. The reachability set is made up of itself and the elements it leads to; on the other hand, the antecedent is made up of itself and the elements it influences. We use the same approach for all entries in the intersection set to extract common values from both the reachability and antecedent sets. The elements in which reachability and antecedents are determined to be the same are allocated (level 1). Then, to eliminate redundancy, the allocated element levels are removed. This procedure is repeated for the remaining elements until each element has at least one level assigned.

Step 5. ISM Model Formulation

Following splitting, a structural hierarchy model of all barriers is developed. The partitioning method aids in the construction of each level of hierarchy, indicating their relative importance. In the hierarchy model, the top level is considered a weak driver due to its limited influence on lower parts. The bottom-level elements are the most crucial. The elements in the model's centre act as a link between the top and bottom levels. Figures 4 illustrate the ISM model for barriers.

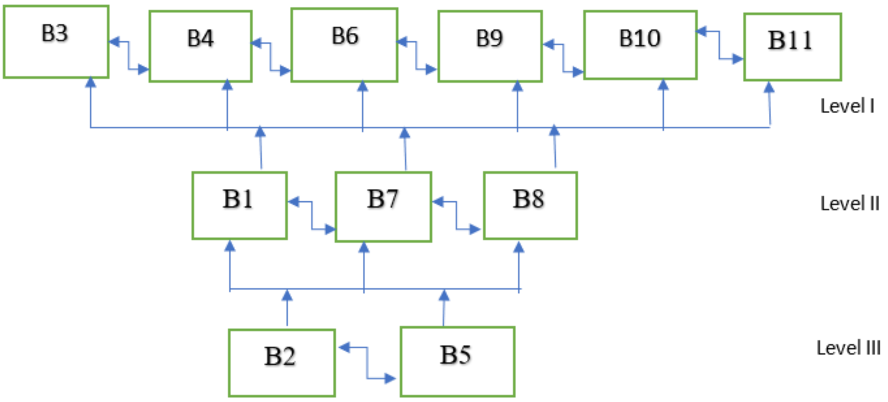

Figure 4. ISM Model for Barriers

4.3.4 MICMAC Analysis

Matrice d'Impacts Croises Multiplication Appliquee aun Classification, or MICMAC analysis in its abbreviated version, is typically used to analyse a group of elements or factors on the basis of their driving and dependence powers. The dependence power factor expresses the effect of other factors on the dependent variable, whereas the driving force expresses the variables that are driven by the dependent variable. As depicted in Figure 5, the barriers revealed were classified into four quadrants based on their driving and dependence power as determined by MICMAC analysis.

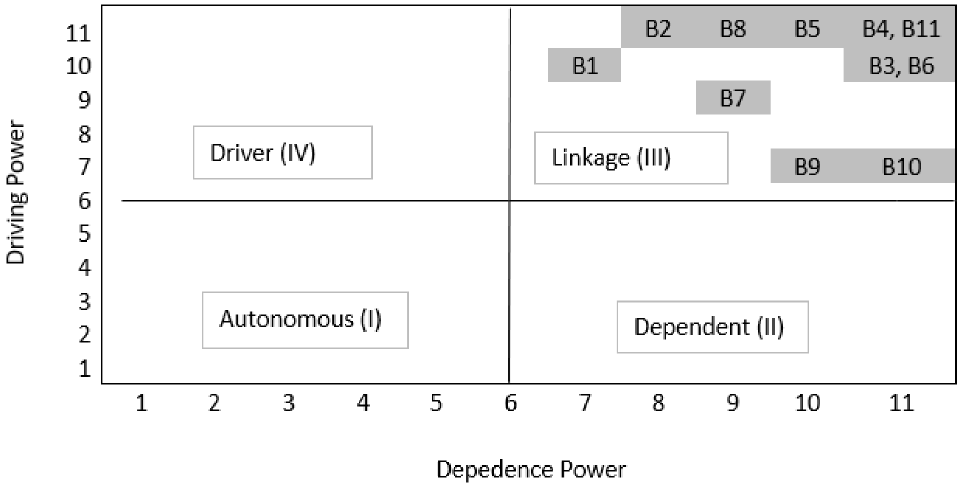

Figure 5. MICMAC Analysis of the Barriers

Autonomous: These are the variables with a low degree of dependence and a low driving force. No variable in this study falls within this category of barriers.
Dependent: These are the variables that have a low driving force but a high degree of dependence. As a result, they are dependent on other variables and are influenced by them. In this research, there are no dependent barriers.
Linkage: These are the variables that have a high driving force and a high degree of dependence. These variables are intrinsically unstable due to the fact that any action on them has an effect on others and a feedback effect on themselves. All of the barriers identified in this study are linkage barriers.
Driver or Independent: These are the key variables that have a high driving force but a low dependence. These are the primary factors, and they have the ability to influence the behaviour of other components.

5. Discussion

In this study, the barriers to the adoption of GM in the Ethiopian context were examined. The introduction section defined three study objectives. The following discussion is made with the purpose of achieving the research objective.

Research Objective 1. Determining the barriers to GM

A comprehensive assessment of the literature discovered a number of barriers. Following that, the list of identified barriers was submitted to eight experts, who were requested to add or delete any elements that were missing from their perspectives. Finally, eleven barriers were determined to be worthy of further investigation. A questionnaire survey with a likert scale was conducted in Ethiopia's manufacturing industry to elicit their input on barriers. There were 90 valid responses received. Next-level analysis was performed on barriers, with a mean value of 2.5.

Research Objective 2. Prioritizing and modelling the barriers to GM

To prioritise barriers, the FAHP approach was used. Table 7 summarises the results of the FAHP analysis. The top-ranking barriers include 'lack of research and development facility (B11)' and 'lack of in-house knowledge on environmental issues (B5)'. Consistent with Rodriguez and Wiengarten's (2017) results, the conclusion indicates that R&D is a significant barrier and that strengthening it will aid in overcoming several associated barriers. Lack of understanding is a significant impediment to the adoption of the GM idea in Ethiopian manufacturing firms. When implementing the GM strategy, it is critical for both managers and employees to have adequate information and training; only then can a green mentality be maintained (Balasubramanian, 2012). A sensitivity analysis is performed following FAHP. The change in ranking as a result of changing the weights of the barriers is depicted in Figure 2 for various scenarios. As illustrated in Figure 2, there is some degree of consistency. In certain instances, the middle barriers' ranks have shifted by a reasonable amount, while the top and bottom barriers' positions have remained nearly unchanged.

ISM-MICMAC approaches were used to model barriers. Figure 3 illustrates the ISM model for the barriers. According to the model, 'Financial constraints (B2)' and 'Lack of in-house knowledge regarding environmental issues (B5)' are the critical barriers to GM adoption, as they are at the model's base and drive all other barriers. Financial constraints and excessive expenses are commonly recognised as important impediments to the implementation of any endeavour in the academic literature (Jadhav et al., 2014; Aboelmaged, 2011). The results of this study are in line with research findings that have been widely publicised in the academic literature.

As illustrated in Figure 4, MICMAC analysis classifies all barriers into four groupings. Because no obstacles fall within the autonomous quadrant, all of the barriers in the study are inextricably linked to the system and form an integral part of it. All barriers in this research are classified as part of the linkage cluster. If the majority of the components in the MICMAC analysis are classified in the 'Linkage' quadrant, it implies that the system under investigation is not resolved and is attempting to make sense (2021, Basit).

5.1 Managerial Implication

The findings of our research have significant implications for managers in Ethiopia's manufacturing businesses who are responsible for implementing GM practises. This research will assist practitioners in identifying the most essential barriers of GM. By weighing the relative relevance of barriers, they can develop effective methods for resolving the issue. Practitioners should work quickly to address high-ranking barriers. For instance, this research discovered that a dearth of research and development is the primary reason for failures in the acceptance of GM techniques. As a result, there is an overwhelming requirement to prioritise R&D in order to address all linked issues. It is recommended that managers devote resources to research and development in order to properly deploy GM practises. As with research and development, practitioners should consider additional important impediments to GM deployment and take appropriate action to overcome them. Additionally, the findings imply that public awareness about the necessity of adopting green products in daily life must be raised.

6. Conclusions

GM practises have been seen as a long-term solution because of the many benefits they bring to all types of manufacturing businesses (Sangwan & Choudhary, 2018). As a result of this research, the barriers to implementing GM practises in Ethiopian manufacturing industries are identified, evaluated, ranked, and modelled. The study identified 11 barriers to GM implementation based on a review of the literature and expert opinion. The study then ranked barriers and highlighted their causal links, utilising a novel integrated technique of Survey-FAHP-ISM-MICMAC. The top-ranking and crucial barriers are 'lack of research and development facility (B11)' and 'lack of in-house knowledge on environmental issues (B5)'. A sensitivity analysis is also performed following FAHP to determine the method's efficacy and the outcome's stability.

This research contributes in a unique way. To begin with, this research contributes to our knowledge of the barriers to GM deployment in Ethiopia. There is a lack of research in developing countries. Second, we

developed a novel integrated Survey-FAHP-ISM-MICMAC strategy. This method of integration has not been employed previously and provides a thorough comprehension of the study's subject.
While the study adds significantly to the body of knowledge, it also has drawbacks. For example, because it is impractical to address all barriers simultaneously, this work assists industry professionals and policymakers in developing appropriate strategies that prioritise critical barriers that play a critical role in enhancing GM practises and issues in the manufacturing sector. A subsequent study might be conducted in collaboration with a public sector expert and utilising a large-scale survey to validate and prove the generalizability of these findings. Additionally, it is advised that a comprehensive framework for GM implementation be developed.

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