Chapter 3
Sustainable Material Selection for Indian Manufacturing Industries: A Hybrid Multi-criteria Decision-Making Approach

Anbesh Jamwal, Rajeev Agrawal, Monica Sharma, and Anil Kumar

Abstract At the present time, Sustainable materials play an important role to make the balance between environment and manufacturing. Many strategies and models have been developed in this field to improve the cost effectiveness in industries. In the last few years Govt. policies among the global and customer pressure has forced many industries to adopt sustainable materials for the manufacturing processes in industries to promote sustainability and maintain the eco balance. The increase in global carbon emission through the manufacturing processes has also forced Indian industries to adopt sustainable practices in their business. Among these, all strategies selection of sustainable materials plays an important role in the adoption of sustainable manufacturing practices in industries. The aim of this research work is to propose a Hybrid Multi-criteria-based model to evaluate the best sustainable materials for Indian manufacturing industries as India is a fast growing nation at the global level. The indicators are collected from an existing literature review and through the questionnaire survey circulated to Indian manufacturing industries. The proposed model of sustainable materials adoption is validated with a case study in the Indian additive manufacturing industry. In the end, this study concludes with the limitation, managerial implications, and future scopes. It is expected that this study will be helpful for Indian manufacturing industries which are adopting sustainable materials in their manufacturing processes.

Keywords Sustainable manufacturing · Sustainable materials · Additive manufacturing · Materials selection · Fuzzy-TOPSIS

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3.1 Introduction

The manufacturing industries in India have a great effect on our environment, economy, and health [1]. The rapid urbanization among the globe has led to many environmental problems such as resource depletion which affect our environmental sustainability [2]. Developing nations like India are working on new innovations and technologies to compete with developed nations [3]. Besides this, Indian industries are now working on maintaining the environmental sustainability to reduce carbon emissions during the manufacturing processes [4]. Sustainability manufacturing focuses on the manufacturing practices which don't or having less effect on the environment during practices [5]. Generally, manufacturing practices in industries produce many types of emission in which carbon emission is the cause of worry at the present time because it is responsible for global warming and environment pollution [6]. Sustainable manufacturing focuses on reducing these emissions during the manufacturing practices in industries. Global policies and customer pressure among the industries have forced all types of industries to adopt sustainable manufacturing practices [7]. Sustainable manufacturing also focuses on the use of those manufacturing processes which don't lead to any health issues for customers and employees as well as other communities [8]. The main drivers of sustainable manufacturing are conservation of natural resources, recycling the products, waste management, and environmental protection using environmentally friendly processes, pollution control using fewer carbon emissions [9]. There are many enablers of which decide the sustainability of the organization in which: Sustainable design, sustainable materials selection, sustainable machining, sustainable packaging, sustainable supply chains, sustainable material disposal, and sustainable recycling are important. Sustainable material selection is an emerging research area in India because inappropriate material selection for manufacturing processes causes higher carbon emissions hence results in environmental pollution [10]. Another reason for sustainable material selection is that now Indian customers are more conscious about the environmental and economic issues so industries are now under pressure to adopt sustainable materials [11, 12]. Apart from these issues, manufacturing industries in India are now considering the material selection process as an important part of the manufacturing and considering as sustainability pillar [13, 14]. The present manufacturing trend across the globe is not only about the financial benefits to the industry but industries are also focusing on the long-term impact of manufacturing on present and future generations by sustainable manufacturing. The term sustainable manufacturing is focused on the consideration of all three pillars of sustainability i.e. economic, social and environmental during the manufacturing and reduction of carbon emissions by promoting eco-friendly manufacturing processes.

1. The objective of present research work is to identify the criteria list for sustainable materials selections for Indian additive manufacturing industries from the survey and literature review which is based on Indian manufacturing industries.
2. Ranking of criteria based on the data collected from the additive manufacturing industries.

3. Prioritize the materials used in additive manufacturing industries with the consideration of sustainability pillars with the help of Fuzzy-TOPSIS methodology.

To meet the present objectives of the study Fuzzy-TOPSIS methodology is used. In Sect. 2 sustainable manufacturing studies have been mentioned in additive manufacturing industries. Section 3 consists of the problem description. Section 4 consists of the solution methodology used in the present study. Section 5 describes the research design and Sect. 6 describes the application of Fuzzy-TOPSIS in the material selection in Indian additive manufacturing industries which is further followed by results and conclusions.

3.2 Research Gap

The use of sustainable powders and materials in the additive manufacturing industries has a very large market at the global level. However, it is limited in developing countries like India due to a lack of a proper framework for material selection [15]. There has been a lot of research work carried out in sustainable materials in the past few years [16–19]. These studies were focused on the selection of sustainable materials which leads to the production of sustainable products through additive manufacturing [20, 21]. Few studies show the issues in sustainable manufacturing in additive manufacturing industries but there is no study that is carried out for sustainable material selection for additive manufacturing industries in a developing nation like India [22]. This study is first attempt to develop a hybrid framework for sustainable material selection for additive manufacturing industries in India which is based on all three pillars of sustainability. In this study, various materials and powders were used in additive manufacturing industries that have been taken and then through the TBL criteria of sustainability best among the alternatives is selected. The criteria and materials were chosen with the consultation with experts from additive manufacturing industries and researchers currently working on additive manufacturing.

3.3 Additive Manufacturing Industry Case Illustration

In the present study case study has been in the additive manufacturing industry. Data of various metals used in the additive manufacturing industry is collected from the industry and then specific values of their mechanical and physical properties are collected from databases. Further, the three all the factors have been categorized into the three categories which are based on the sustainability measurements. In Indian additive manufacturing industries, sustainable manufacturing studies are reported and there is no study that reports about the sustainable material selection for the Indian additive manufacturing industries. From the literature survey, it is found that

Table 3.1 Criteria for the additive manufacturing industries

Criteria	Symbol
Environmental	ENV
Social	SCO
Economical	ECO

developed countries are now focusing on the adoption of sustainable materials over the traditional materials to reduce the negative impact of manufacturing processes on the environment. Sustainable practice around the globe has forced developing nations like India to adopt sustainable material selection but in Indian industries, there are no proper criteria for the sustainable material selection for additive manufacturing industries. In the present study, there are 19 alternatives were chosen with 3 criteria with the discussion with additive manufacturing experts and academia. Further, the questionnaire survey is circulated to the industry and academia to collect the data. Inputs given by experts were processed and ranking of criteria and alternatives is done with the fuzzy-TOPSIS. Tables 3.1 and 3.2 show the alternatives and criteria chosen for the study.

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Table 3.2 Alternatives for sustainable material selection for industries

Alternative	Symbol	Criteria
Global warming contribution	ENV1	ENV
Healthy industry environment	ENV2	ENV
Environment form	ENV3	ENV
Waste management	ENV4	ENV
Transportation and production activities	ENV5	ENV
Recycle and reuse	ENV6	ENV
Natural resources consumption	ENV7	ENV
Land occupied	ENV8	ENV
Health and safety	SCO1	SCO
Ecological and social acceptability	SCO2	SCO
Availability and adaptation	SCO3	SCO
Political issues	SCO4	SCO
Resistance against natural contamination	SCO5	SCO
Maintenance and operation cost	ECO1	ECO
Investment cost	ECO2	ECO
Energy efficiency	ECO3	ECO
Financial risks	ECO4	ECO
Tax contributions	ECO5	ECO
Meeting volatile customer demands	ECO6	ECO

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3.4 Solution Methodology

Generally, the conventional TOPSIS method discussed the identification of the best alternative among the number of alternatives and criteria using the shortest distance from the negative ideal solution of the problem and the positive ideal solution of the problem. In general, a positive ideal solution gives the maximum benefit to the industry at the minimum cost and in a negative ideal solution, it is reversed [23, 24]. The distinguishing feature of the Fuzzy-TOPSIS method as compared to the TOPSIS method is that in place of crisp weights for the alternatives and criteria. Triangular fuzzy numbers used in the problem to represent the linguistic judgement of experts from industry and academia. In the present section, the Fuzzy TOPSIS methodology is proposed [25]. The only limitation of the traditional TOPSIS technique is that the crisp inputs are used for the selection of the alternative. There may be imprecise human judgement due to the crisp inputs raking of the alternatives. Steps of fuzzy-TOPSIS techniques are discussed below:

a. Develop a comparison matrix (m_{ij}) of the alternatives with the different criteria by the use of linguistic variables presented in Table 3.5.
b. Obtain the normalized decision matrix by using the equation presented below:

$$r_{m_{ij}} = \left\{ \begin{array}{ll} \left(\frac{a_{m_{ij}}}{x_{ij}^{+}} + \frac{b_{m_{ij}}}{x_{ij}^{+}} + \frac{c_{m_{ij}}}{x_{ij}^{+}} \right), & \forall_{ij}, x_{ij}, \quad is\ a\ positive\ criterion \\ \left(\frac{x_{ij}^{-}}{a_{m_{ij}}} + \frac{x_{ij}^{-}}{b_{m_{ij}}} + \frac{x_{ij}^{-}}{c_{m_{ij}}} \right), & \forall_{ij}, x_{ij}, \quad is\ a\ negative\ criterion \end{array} \right\} \tag{3.1}$$

c. Obtain a weighted normalized decision matrix using the equations given below:

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n} \tag{3.2}$$

$$\widetilde{v_{ij}} = r_{m_{ij}} \otimes w_j \tag{3.3}$$

d. Determine the FNIS (Fuzzy negative ideal solution) and FPIS (Fuzzy positive ideal solution) as follows:

$$A^- = \left\{v_1^-, v_2^-, \ldots, v_n^-\right\}, \quad where$$
$$v_j^- = \{\max\left(v_{ij}\right) if j_{\varepsilon j}; \min\left(v_{ij}\right) if j_{\varepsilon J'}\}, \quad j = 1, 2, \ldots, n. \tag{34}$$

Here, J' is the negative criteria.

$$A^+ = \left\{v_1^+, v_2^+, \ldots, v_n^+\right\}, where$$
$$v_j^+ = \{\max\left(v_{ij}\right) if \quad j_{\varepsilon j}; \min\left(v_{ij}\right) if \ j_{\varepsilon J'}\}, \quad j = 1, 2, \ldots, n. \tag{3.5}$$

Here, J' is the positive criteria.

e. Calculation of distance from each alternative FNIS and FPIS as follows:

$$d_i^- = \left\{\sum_{j=1}^{n}(v_{ij} - v_{ij}^-)^2\right\}^{1/2}, where \ \ i = 1, 2, \ldots, m. \tag{3.6}$$

$$d_i^+ = \left\{\sum_{j=1}^{n}(v_{ij} - b_{ij}^+)^2\right\}^{1/2}, \quad where \ \ i = 1, 2, \ldots, m. \tag{3.7}$$

f. Calculation for (CC_i) closeness coefficient for each alternative as follows:

$$CC_i = \frac{d_i^+}{d_i^- + d_i^+}, \quad i = 1, 2, \ldots, mCC_{i\varepsilon} \tag{3.8}$$

g. Ranking of alternatives for the material selection by CC_i values in the descending order.

3.5 Application of Methodology

This section illustrates the application of Fuzzy-TOPSIS in the selection of sustainable materials for Indian additive manufacturing industries. In the first phase, the data is collected from the industries using the questionnaire survey and a sustainable model is developed to select the best sustainable material for industries which is based on the TBL. The criteria and alternatives for the present study are finalized through the discussion with the expert reviews. 3 criteria with the 19 alternatives

Table 3.3 Linguistic expressions

Linguistic variables	Corresponding Fuzzy number
Very low	(0, 0, 2)
Low	(0, 2, 4)
Medium	(2, 4, 6)
High	(4, 6, 8)
Very high	(6, 8, 10)
Excellent	(8, 1, 10)

Table 3.4 Pairwise comparison for different criteria

Criteria	Environmental	Economical	Social
Best criteria: environmental	1	5	7
Environmental			7
Economical			5
Social			1
Worst criteria: social			

were selected for the study. The linguistic expression used in the present research work is shown in Table 3.3.

Table 3.8 shows the main criteria's computational results; CR value of main criteria is less than zero which is due to the high consistency among the pairwise comparison (Tables 3.4, 3.5, 3.6 and 3.7).

Table 3.5 Pairwise comparison for environmental criteria

BO	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7	ENV8
Best criteria: ENV1	1	4	8	3	4	4	5	8
ENV1								8
ENV2								6
ENV3								1
ENV4								4
ENV5								5
ENV6								4
ENV7								4
ENV8								5
OW	Worst criteria: ENV3							

Table 3.6 Pairwise comparison for social criteria

BO	SCO1	SCO2	SCO3	SCO4	SCO5
Best criteria: SCO4	2	3	3	1	4
SCO1					6
SCO2					6
SCO3					5
SCO4					7
SCO5					4
OW	Worst criteria: SCO5				

Table 3.7 Pair-wise comparison for the Economic criteria

BO	ECO1	ECO2	ECO3	ECO4	ECO5	ECO6
Best criteria: ECO5	5	3	2	4	1	2
ECO1						5
ECO2						5
ECO3						6
ECO4						4
ECO5						7
ECO6						4
OW	Worst criteria: ECO6					

Table 3.8 Criteria weights with CR

Criteria	ξ*	Weights	CR
Environmental		0.69221	
Social	2.00222	0.07680	0.53661
Economical		0.23085	

3.6 Results and Discussion

The results obtained from the present research work and application of Fuzzy-TOPSIS methodology is presented in Figs. 3.1, 3.2 and Table 3.9. Table 3.9 represents the results obtained from the application of the proposed methodology. In the present study three main pillars of sustainability: Economic, social and environmental is considered which the TBL are also. In this study weights for criteria and alternatives are determined using the best worst method and the global weights of alternatives have been calculated. Among all the three criteria it is found that the environmental aspect has a great influence on additive manufacturing industries rather than the other two aspects. It is found that in developing nations like India environmental factors are important factors that influence the sustainability issues in industries. The depletion of natural resources affects the environmental balance. It is a major issue for the

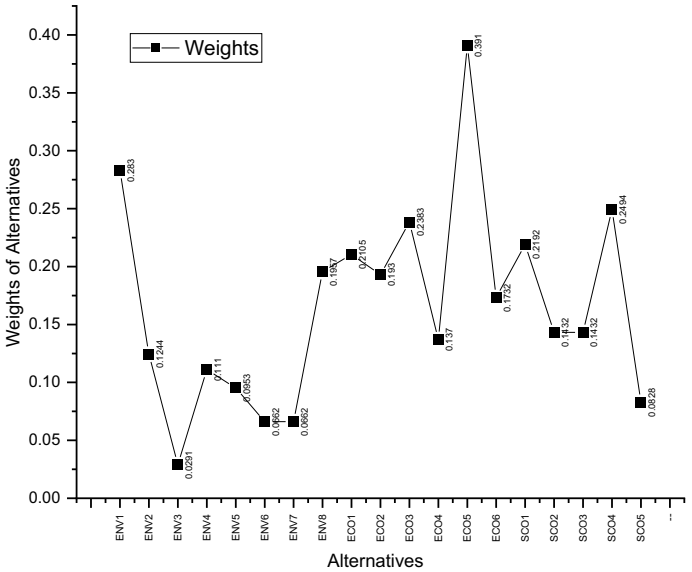

Fig. 3.1 Alternatives weights for sustainable material selection

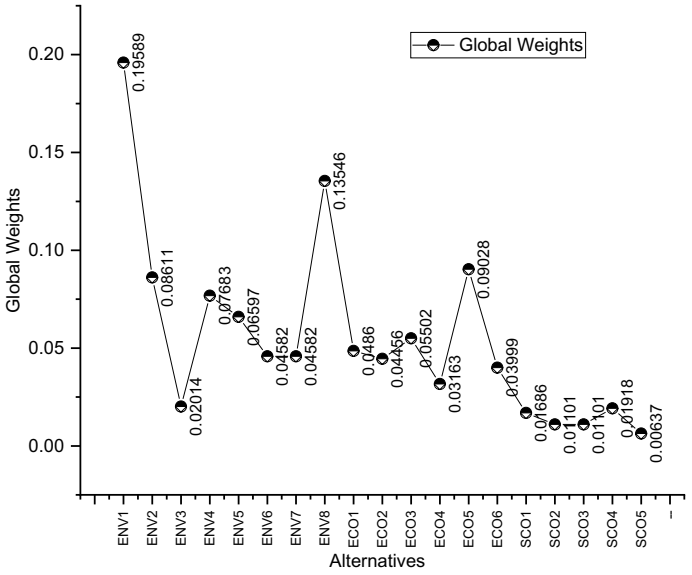

Fig. 3.2 Global weights of alternatives

Table 3.9 Ranking of alternatives with their respective criteria

Alternative	Symbol	Criteria	Rank
Global warming contribution	ENV1	ENV	1
Healthy industry environment	ENV2	ENV	4
Environment form	ENV3	ENV	14
Waste management	ENV4	ENV	5
Transportation and production activities	ENV5	ENV	6
Recycle and reuse	ENV6	ENV	9
Natural resources consumption	ENV7	ENV	10
Land occupied	ENV8	ENV	2
Health and safety	SCO1	SCO	16
Ecological and social acceptability	SCO2	SCO	17
Availability and adaptation	SCO3	SCO	18
Political issues	SCO4	SCO	15
Resistance against natural contamination	SCO5	SCO	19
Maintenance and operation cost	ECO1	ECO	8
investment cost	ECO2	ECO	11
Energy efficiency	ECO3	ECO	7
Financial risks	ECO4	ECO	13
Tax contributions	ECO5	ECO	3
Meeting volatile customer demands	ECO6	ECO	12

industries to meet the demands of customers while considering the environmental factors and following the standards. Sustainability plays an important role to fulfill the customer requirements while reducing the negative impacts of processes on the environment. The ranking of criteria is ENV > ECO > SOC in our sustainable model for material selection for Indian additive manufacturing industries. In this study, it is found that environmental factor consideration should be given more importance for Indian manufacturing industries for sustainable manufacturing practices in the additive manufacturing industries. In the last few years, there have been many advancements in processing techniques for the materials for additive manufacturing purposes, especially for metal additive manufacturing. The environmental criteria having eight alternatives which can be ranked as ENV1 > ENV8 > ENV2 > ENV4 > ENV5 > ENV6 > ENV7 > ENV3. The effect of global warming due to additive manufacturing ranked one among all the alternatives. It is found that conventional materials contribute to large CO_2 emissions and other environmental problems that can be solved by the use of sustainable eco-friendly materials. In a healthy industry, the environment is which also affects the sustainability practices in Indian additive manufacturing industries. Choosing the right criteria for Indian manufacturing is a challenging task as it requires a validated model with less cost. The economic criteria alternatives are ranked as ECO5 > ECO3 > ECO1 > ECO2 > ECO6 > ECO4.

Based on the data collected from the industries and academia experts tax contribution plays an important role in sustainability practices. It is further followed by energy efficiency. Indian industries are now focusing on the adoption of sustainable manufacturing practices [26, 27]. Sustainable materials plays an important role in Sustainable manufacutring practices [28, 29]. This is the reason now industries are more focused towards the adoption of sustainable materials and machining methods.

Renewable sustainable energy sources have very little impact on the environment. Ranking for the social criteria is SOC4 > SOC1 > SOC2 > SOC3 > SOC5. It is found that political issues are a very important factor for Indian additive manufacturing industries which is further followed by health and safety.

The main aim of the present research work is to develop a sustainable model for the material selection for Indian additive manufacturing industries with the consideration of TBL. The criteria and alternatives in present research work are ranked by the Fuzzy-TOPSIS method.

3.7 Conclusion and Future Scope

The present concept of sustainable development is becoming more popular in developing nations like India due to Govt. polices and pressure from consumers to considering environmental factors. With an increase in the population of India pollution is also increasing day by day which also results in depletion of natural resources at a very fast rate. Indian industries are the large contributors in the world industrialization in which some are following sustainable manufacturing practices. But these studies are very limited especially when it comes to additive manufacturing industries. It is still a major problem for the Indian industries to select sustainable materials with the concept of sustainable development. In the present paper, a framework is developed and proposed for the Indian additive manufacturing industries with the consideration of TBL. There were 3 criteria with 19 alternatives finalized after the survey and then the BWM method is considered for the weight calculations. The last phase of the study is about the ranking the alternatives by Fuzzy-TOPSIS method. It is expected that this study can provide a sustainable model for the material selection for the Indian additive manufacturing industries.

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