



Vol. XI & Issue No. 6 June - 2018

INDUSTRIAL ENGINEERING JOURNAL

GREEN MANUFACTURING SUPPLIER EVALUATION CRITERIA USING PRINCIPAL COMPONENT ANALYSIS

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Abstract

Recently the world has switched towards the concept of sustainable green production, because globe has experienced the significance of environment for the growth of mankind. The intention of this study is to recognize sustainable and green manufacturing factors during supplier evaluation in the Indian manufacturing sector. Almost all industries favor the concepts of sustainable development, owing to which 'green supplier evaluation' has evolved itself as the major role in this regard. There are so many factors considered for this research. On the basis of these factors 'green supplier evaluations' has been carried out. The results can be deployed in any manufacturing industry. This research has finalized the criteria for 'green supplier evaluation'. It is difficult to select criteria for the evaluation among the available. The factor analysis technique is employed for this research. This technique finds the latent variables from the different criteria short out from literature survey. The factor analysis is carried out by SPSS software.

Keywords— Green Supplier, principal component analysis, green supply chain management

I. INTRODUCTION

The significance of sustainable supplier evaluation is more now a day because almost all industries are facing problem related to like; environment factor, government regulation etc. Presently everybody is aware for environmental and wants to care of environmental factors and safety policies acts. There are many suppliers which ignores the acts of related to safety health regulations and environment factors. This research identifies the sustainable supplier evaluation criteria's and their selection. Also, how it can be apply.

The objective of this research is to identify the powerful criteria of efficient sustainable supplier evaluation for manufacturing industries as well as sectors. The identified factors are powerful tool for sustainable supplier evaluation with the green manufacturing approach, which can be implemented in any manufacturing firm. The questionnaire is designed after reviewing number of articles. After the literature survey the below criteria has been selected for sustainable green supplier evaluation.

During the I-phase of questionnaire, the opinions of industrial workers and consultants were taken. Later, based on their feedbacks and opinions the criteria were modified and re-structured with sub criteria and subsequence applying factor analysis technique. Following are the objectives of the research:

1. To Identify the scope of Sustainable and GSCM in Indian as well as other countries industries;
2. To Identify the implementation of sustainable green supplier evaluation in Indian as well as other countries industries;
3. To Identify the important factors sustainable green supplier evaluation in Indian as well as other countries industries;

II. LITERATURE REVIEW

Sustainable GS is known as improved and developed SCM which can be apply on all industries [4]. The function(s) of ESCM includes; how to reuse and recycle product as well as

materials [5]. Many organizations worked for supplier selection and evaluation. They suggested which criteria are important to particular type of firm.

GSCM and EM are newly areas. There are so many organization worked on it [6].

According to reference [7], key focus of GSCM and EM is to make business orientation eco-friendly:

1. To integrate the GSC into corporate policies and strategies for trouble free operations.
2. Aware most important criteria for manufacturing sector to evaluate supplier.
3. To show how important it is to save environment and sustain the natural resources and give an idea about at what level the business activities dependent on environment.

According to reference [8], the increased collaboration of environmental consideration in OM and SC has turned out to be important sector. Reference [9] has explored in their research study that the important GSCM should apply by considering the environmental factors in *supplier Evaluation, maintenance and development*. According to reference [10] the supplier selection and evaluation process shows a set of activities such as identifying, analyzing, and choosing the efficient suppliers to become the supply chain. Suppliers who adopt GSCM practices can develop the environmental factor, performances of manufacturing sector etc. which strong the firm and company(s) throughout the SC. These selected criteria for sustainable supplier evaluated in regards of related firm.

In this research, criteria for GSC evaluated are being adopted from the Gunasekaran & Ngai's research [7] and Kothari [12]. Table 1 shows the details of green supplier selection criteria:

Table 1: Details of supplier selection criteria

S.No.	Green Supplier Selection Criteria	Reference
1	Design of products for optimum consumption of material/energy	[12]
2	Cooperation and feedback with customer in developing eco design	[12]
3	Importance of recycling product design from supplier	[12]
4	Product's design meet environmental regulations and safety standards	[12]
5	Degree of use of environment friendly technology by supplier	[12]
6	Degree of use of environment friendly materials by supplier	[12]
7	Product design and developed for ease in dismantling and re manufacturing	[12]
8	Renewable product design of supplier	[12]
9	Possibility of eliminating secondary processes considered	[12]
10	Degree of use of recycled material for packaging material considered	[12]
11	Packaging material disposal planned	[12]
12	Minimizing the use of packaging considered	[12]
13	Product recycling rate	[12]
14	Importance of having reverse logistic system of suppliers	[12]
15	Consideration of reduction in set up times	[12]
16	Minimizing toxic/ hazardous waste during manufacturing	[12]
17	Considerations of environmental issue in selection of manufacturing processes	[12]
18	Measures taken to reduce material and energy used in manufacturing	[12]
19	Consideration of environmental issue in production planning and control	[12]
20	Optimum energy consumption during manufacturing processes	[12]
21	Minimizing use of natural resources during manufacturing	[12]
22	Possibility of product being recyclable, re usable	[12]
23	Increase of cost in purchasing environmentally friendly materials	[12]
24	Degree of reduction in overall cost of the organization	[12]
25	Degree of reduction in transportation cost	[12]

26	Water and air pollution treatment cost	[12]
27	Energy consumption cost	[12]
28	Acceptance rate of product by customer	[12]
29	Capability of quality management in organization	[12]
30	Degree of having quality related certificates	[12]
31	Capability of handling abnormal quality	[12]
32	Amount of goods delivered on time improved	[12]
33	Extent of process improvement	[12]
34	Warranties and claim policies for customers	[12]
35	Achievement in higher technological level	[12]
36	Improvement in capability of research and development	[12]
37	Achievement of cleanser production	[12]
38	Minimization of air emission and waste water	[12]
39	Optimization of man power resources in production process	[12]
40	Degree of reduction in energy consumption	[12]
41	Cooperation from customers for using less energy during product transportation	[12]
42	Degree of cooperation from customers for green packaging	[12]
43	Degree of cooperation from customers for cleaner production	[12]
44	Degree of cooperation from customers for eco design	[12]
45	Encouragement in giving suggestions on environmental performance	[12]
46	Degree of cooperation with customers for environmental procurement	[12]
47	Degree of customers involvement in process of determining environmental goals	[12]
48	Minimize the amount of hazardous materials used in production of product	[7]
49	Measures taken to reduce material	[7]
50	Water and energy used in manufacturing	[7]
51	Reduced set up times	[7]
52	Minimizing use of natural resources during manufacturing	[7]

53	Minimizing toxic/ hazardous waste during manufacturing	[7]
54	Production schedules	[7]
55	Closed loop manufacturing/ remanufacturing	[7]
56	Backup system	[7]
57	Quality level	[7]
58	Supply chain information sharing	[7]
59	Technology level availability of R& D	[7]
60	Cleaner technology (water, air, energy used)	[7]
61	Technical expertise	[7]
62	Sustainable transportation handling and storage of hazardous materials	[7]
63	Control on inventory	[7]
64	Warehousing	[7]
65	Packaging and facility allocation	[7]
66	Technical support	[7]
67	Re design	[7]
68	Complaint response time	[7]
69	Storage frequency	[7]
70	Warranty	[7]
71	Certification	[7]
72	Raw material	[7]
73	Re use recovery	[7]
74	Re cycle of waste	[7]
75	Emission	[7]
76	ISO 14000 certification	[7]
77	Requirement of green purchasing	[7]
78	Green material coding and recoding	[7]
79	Inventory of substitute material	[7]
80	Supplier management	[7]
81	Capability of green design	[7]
82	Inventory of hazardous substances	[7]
83	Management of hazardous substances	[7]
84	Prevention of mixed materials	[7]
85	Process auditing	[7]
86	Pre shipment inspection	[7]

III. RESEARCH METHODOLOGY

Present research work is based on investigating green supplier evaluation criteria using *principal component analysis* (an

important division of factor analysis technique). Details of factor analysis, principal component analysis techniques are as follows:

1. Factor Analysis

According to reference [13] Factor analysis is the name given to a group of statistical techniques that can be used to evaluate the large variable into underlying dimensions which is selected for this research.

According to Kothari (pp.36) Factor analysis may be R-type factor analysis or it may be Q-type factor analysis. R-type means who score more than other variable which is selected for this research and low rate variable is neglected. In *Q-type factor analysis*, the correlations are computed between pairs of respondents instead of pairs of variables. High correlations occur when respondent 1's pattern of responses on all the variables is almost same the patterns of responses by 2's respondent. Factors emerge, when there are high correlations within groups of people. Those factor obtained high value chosen first [13].

The main difference between *factor analysis* and *principal component analysis* lies in the way the communalities are used. Principal component analysis considered that the total variance of the variables can be accounted by mean value of its components (or factors), and there is no error discrepancy. On the other hand, *factor analysis* does assume error variance. This is revealed in the fact that in factor analysis the communalities have to estimated, which makes factor analysis more complex than principal component analysis, but also further conservative.

The wide range feedback had been collected from various industries. The selected large sampling has minimized. Table 2 presents a summary, below:

Table 2: Different opinions regarding sample size

S.No	Researcher	Sample size
1	[14], [15]	At least 100
2	[16]	At least 200
3	[17]	At least 250
4	[18]	100 = poor, 200= fair, 300=good, 500=very good and 1,000 or more = excellent
5	[19]	At least 50, Preferable 100 or larger
6	[11]	Partly determined by the nature of the data

I. According to Kothari (pp.323), rotation, in the perspective of factor analysis, is a bit similar like discoloration a microscope slide. Just as unlike discolour on it confirm dissimilar structures in the tissue, different rotations extract dissimilar structures in the data. Though unrelated rotations give results that show to be fully different, but from a statistical viewpoint, all outcomes are taken as equal, none superior or inferior to others. However, from the viewpoint of making logic of the results of factor analysis, one should select the right rotation. If the factors are free orthogonal rotation is done and if the factors are correlated,

a slanting rotation is made. Communality for every variable will stay undisturbed regardless of rotation but the eigen values will vary as result of rotation.

IV. CASE STUDY

This research is based on finalization of performance measures for the purpose of green supplier evaluation, determining the interrelationships between them. The research work is *twofold*. Firstly, performance measures are identified using principal component analysis. The various stages involved in the case study are as follows:

1. Obtainment of detailed list of available green supplier Evaluation criteria from available literature on green supplier selection;
2. Finalization of criteria using principal component analysis. Methodology adopted for this research is given as follows:
 1. First of all, a detailed list of available criteria on green supplier evaluation prepared through literature survey available on green supplier selection (please refer Table 3).
 2. In second step, a systematically designed, questionnaire (please refer Appendix - I) was sent to various industries of country to collect the responses. The details of questionnaire are as follows:

Table 3: Details of responses collected for criteria finalization

S.No	Item	Output
1.	Number of questionnaire sent	113
2.	Number of industries covered	63
3.	Number of responses obtained	73
4.	Number of complete responses obtained	60
5.	Response Ratio	64.60%
6.	Region covered	Different provinces of Country

3. The software used for the purpose of criteria finalization was SPSS 16.0. SPSS is one of much renowned software used around the globe for solving statistical problems. The criteria are finalized using the *principal component analysis* technique with *varimax* rotation. In this research the factor loading values is considered below 0.5 to get reliable results. During analysis when data input in the software, it has been observed that there were many principal components with no allocations, with negative factor loadings and furthermore, it was quite difficult to get rotation of data, due to which it was difficult to obtain desired results.

4. On the basis of obtained result, group of criteria formed and proceed for principal component analysis. Again the views of many industrial persons and academicians had been collected and also made discussion in regards grouping of criteria. As a result of series of in formal discussions with them, author(s) has grouped the different criteria in the following manner:

Table 4: Details of grouped variables

S.No	Grouped variables	Component Variables
1	Green Design	Design of products for optimum consumption of material/energy
		Cooperation and feedback with customer in developing eco design
		Importance of recycling product design from supplier
		Product's design meet environmental regulations and safety standards
		Degree of use of environment friendly technology by supplier
		Degree of use of environment friendly materials by supplier
		Product design and developed for ease in dismantling and re manufacturing
		Renewable product design of supplier
		Possibility of eliminating secondary processes considered
2	Green Logistic Design	Degree of use of recycled material for packaging material considered
		Packaging material disposal planned
		Minimizing the use of packaging considered
		Product recycling rate
		Importance of having reverse logistic system of suppliers
3	Green Manufacturing	Consideration of reduction in set up times
		Minimizing toxic/hazardous waste during manufacturing
		Considerations of environmental issue in selection of manufacturing processes
		Measures taken to reduce material and energy used in manufacturing
		Consideration of

		environmental issue in production planning and control
		4Optimum energy consumption during manufacturing processes
		Minimizing use of natural resources during manufacturing
		Possibility of product being recyclable, re usable
4	Green Costs	Increase of cost in purchasing environmentally friendly materials
		Degree of reduction in overall cost of the organization
		Degree of reduction in transportation cost
		Water and air pollution treatment cost
		Energy consumption cost
5	Quality	Acceptance rate of product by customer
		Capability of quality management in organization
		Degree of having quality related certificates
		Capability of handling abnormal quality
		Amount of goods delivered on time improved
		Extent of process improvement
		Warranties and claim policies for customers
		Achievement in higher technological level
		Improvement in capability of research and development
6	Environment performance assessment	Achievement of cleanser production
		Minimization of air emission and waste water
		Optimization of man power resources in production process
		Degree of reduction in energy consumption
7	Customer	Cooperation from customers for using less energy during product

	cooperation	transportation
		Degree of cooperation from customers for green packaging
		Degree of cooperation from customers for cleaner production
		Degree of cooperation from customers for eco design
		Encouragement in giving suggestions on environmental performance
		Degree of cooperation with customers for environmental procurement
		Degree of customers involvement in process of determining environmental goals
8	Manufacturing parameters	Minimize the amount of hazardous materials used in production of product
		Measures taken to reduce material
		Water and energy used in manufacturing
		Reduced set up times
		Minimizing use of natural resources during manufacturing
		Minimizing toxic/ hazardous waste during manufacturing
		Production schedules
		Closed loop manufacturing/ remanufacturing
		Backup system
		Quality level
		Supply chain information sharing
9	Technological parameters	Technology level availability of R& D
		Cleaner technology (water, air, energy used)
		Technical expertise
10	Green logistic performance	Sustainable transportation handling and storage of hazardous materials

	parameters	Control on inventory
		Warehousing
		Packaging and facility allocation
11	Customer service parameters	Technical support
		Re design
		Complaint response time
		Storage frequency
		Warranty
		Certification
12	Environmental management parameters	Raw material
		Re use recovery
		Re cycle of waste
		Emission
		ISO 14000 certification
13	Procurement management parameters	Requirement of green purchasing
		Green material coding and recoding
		Inventory of substitute material
		Supplier management
14	Research and development management parameters	Capability of green design
		Inventory of hazardous substances
15	Process management parameters	Management of hazardous substances
		Prevention of mixed materials
		Process auditing
		Pre shipment inspection
Cronbach's ALPHA=0.8977		

The value of Cronbach's alpha obtained after combination was 0.8977, which governed the combination.

5. In next step of the research, the fifteen grouped parameters were fed to the SPSS software for the purpose of identification of hidden variables among them. For this purpose, the mean values of component variable representing the value of grouped variables are considered. After applying the principal component analysis technique on the data the following results has been obtained.

Table 5: KMO and Bartlett's test result and determinant value

KMO and Bartlett's Test and Determinant Value		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	.363	
Bartlett's Test of Sphericity	Approx. Chi-Square	253.159
Df	105	
Sig.	.000	
Determinant = 8.552E-03		

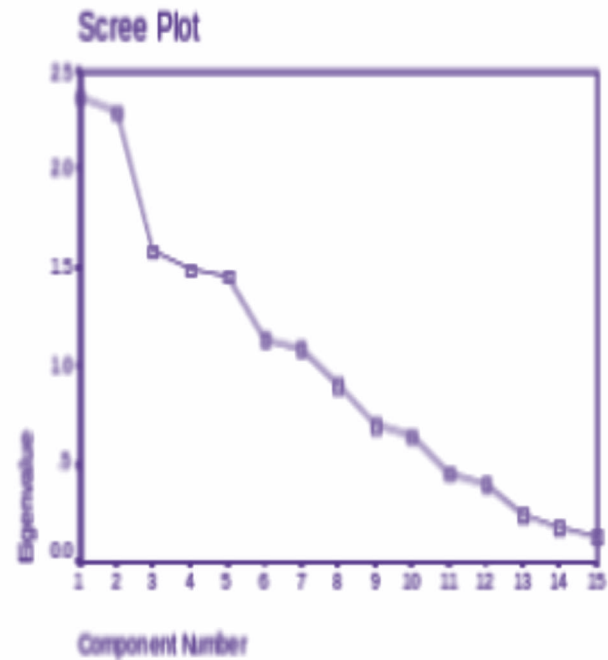


Figure 1: Scree plot

Table 6: Component matrix (un-rotated)

Component Matrix Parameters	Component						
	1	2	3	4	5	6	7
Green Logistic Design	-	.614					
Manufacturing Parameters	-	.598					
Green Design	.553	.533					
Technological Parameters							
Process Management Parameters		-	.760				
Environment Management Parameters		.553	.527				
Customer Service Parameters							

V. DISCUSSION OF RESULTS

As the result of this research, two outputs found. A unique set of seven principal components, abstracting the fifteen criteria is the first output, and the model showing interrelationships between different principal components is the second output. Seven principal components obtained as the result of this research are; research development and manufacturing parameters, environment based logistic operation parameters, technological parameters, customer oriented green design parameters, cost and procurement parameters, quality as a parameter and green logistic design and manufacturing parameter. All these parameters represent different aspects of green supplier selection and cover all the stages of product development as well. These parameters cover twelve out of fifteen criteria. Three criteria, namely, process manufacturing parameters, environmental performance assessment, and customer service parameter were not considered due to discrepancies shown by the criteria at the time of conduction of principal component analysis. Criteria process manufacturing parameters, environmental performance assessment were omitted from final output due to their negative factor loadings of 0.763, and 0.536 respectively, and the criteria customer service parameters was removed due to its no factor loading in the analysis.

Reliability analysis of the components is also conducted to assure the adherence of the variables to the principal components. In reliability analysis, *cronbatch's alpha* approach is being used. The value of *cronbatch's alpha* is varying from 0.3405 to 0.5607 for components. The reason for such lower values is low response rate.

Some components like; *technological parameters*, and *quality* with *nil* alpha value has selected. The reason behind the selection of these parameters is the higher factor loading values of the principal components. The principal *components technological parameters* and *quality* were alone and when combined, the value of *cronbatch's alpha* calculated for the pair, the resulted value was - 0.2399, which is impracticable. Therefore, it is decided to leave these principal components alone and consider for analysis.

VI. CONCLUSIONS

This research work mainly concentrates to identify the parameters responsible for green supplier evaluation and develop interrelationships between the parameters. The conclusions drawn at various stages of this research are followings:

(1) First of all, criteria have been identified and a detailed list of criteria prepared, thereafter a systematically designed, questionnaire sent to industrial persons and academicians to collect their responses. Using principal component analysis technique the hidden variables are identified. Also, in first solution a lot of missing factor or loading values obtained. At this point, it is realized and concluded that, while conducting principal component analysis, proper attention must be paid towards missing values during investigation. In absence of which it may lead the research in wrong direction. It is suggested through this research to industrial persons, who are

not much aware towards green supply chain evaluation parameters; they also can refer these parameters for green supply chain evaluation.

(2) Grouping of variables converted into main parameters in case of absence of statistical data. In this case weightage must be given to that parameters which are suggested by industry personal and academicians. Also, concluded that a clubbed variable must reflect all the component variables.

(3) Through this research, it is observed that, some industries like chemical industries, leather industries, and tyre manufacturing industries are much aware regarding green supplier evaluation.

(4) After principal component analysis of refined data, it has been concluded that physical significance and importance of a component should be considered in the principal component. For this, the suggestions and responses of academicians and industry (5)personnel were useful. Because of this, two principal components namely, technological parameters, and quality are added in this research.

(6)After investigation of the relationships between principal components, it is concluded that if focus is on driving variables than the desired values of dependent variables can be find very easily.

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