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INNOVATION-DRIVEN ENVIRONMENTALLY-BENIGN MANUFACTURING: A CASE STUDY

S. Singh[1] and S.P. Lal[2]

[1]Professor, School of Mechanical Engineering, KIIT University, Bhubaneswar-751024,Odisha,
Email: saranjit_singh@outlook.com
[2]Professor, Department of Production Engineering, BIT Patna, Patna-800014, Bihar,
Email: splal@yahoo.com

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Abstract: Modern organizations should consider environmentally-benign manufacturing as an innovation opportunity and in order to accomplish that, a handy model, based on industrial situation is required. In the present paper, an attempt has been made, to formulate a simple innovation-driven environmentally-benign manufacturing model, which is capable of performing comprehensive assessment of the sustainability status of the manufacturing organizations. It is based on the case study of the innovation-driven industrial pollution control equipment used by steel industries. It is expected that the model will be of immense importance, as it will enable the manufacturing organizations to post-mortem their past performance and plan their future operations with an emphasis on the innovative environmentally-benign practices effectively.

Keywords: Innovation, Environmentally-Benign Manufacturing, Sustainability, Modeling

1. INTRODUCTION

Environmentally-benign manufacturing is defined as the developing technologies to transform materials without the emission of greenhouse gases, the use of non-renewable materials or the generation of wastes [1]. The options to accomplish the objectives of the environmentally-benign manufacturing are [2]:

- use less materials and energy
- substitute for input materials, i.e. non-toxic for toxic and renewable for non-renewable
- reduce unwanted outputs, i.e. adopt cleaner production and advocate industrial symbiosis
- convert outputs to inputs i.e. recycling of all variants

The integration of environmentally-benign thinking into business processes of an organization, should be viewed as a creative opportunity, in the best interest of their business. Firms, whose products and services receive quick acceptance from the society and create solutions to the environmental problems, will benefit and succeed in the long run. Firms have to be clear on the understanding of their values like giving precedence to sustainability& environment-friendliness, understanding market opportunities& drivers, regulatory requirements, ecology-based demands, efficiency opportunities, as well as expertise in the emerging and innovative technologies that reduce the resource consumption and environment burden. All these will drive the innovative technologies within the firm [3-5]. Innovation as a driver for the environmentally-benign manufacturing can be described as an eco-innovation, which looks at removing the trade-offs between environmental, social and economic concerns, by finding innovative win-win solutions through new technologies [6-8]. Greener technologies driven new engineering applications will only be possible if economic, social and institutional innovations keep pace with the technological innovations. This will not only transform the existing products, but will also lead to major changes in the process know-how used to the manufacture such products in the industries. Innovation has the potential to underpin competitive advantage, and a linkage with the environmentally-benign manufacturing will reap greater benefits [9-12].

In order to assess its status in the organizations, a handy model is therefore necessary. In the present paper, an attempt has been made to develop an innovation-driven environmentally-benign manufacturing model, which is not only simple and manageable, but also capable of assessing sustainability status of manufacturing organizations. The formulation of the model is based on a suitable case-study of the innovation-driven industrial pollution control equipment used by different steel industries [13]. The model involves selection and classification of various indicators of sustainability, to arrive at an average sustainability index. It uses the costs associated with various innovations, their adoption time and respective occurrence time. Finally, the organizations are ranked according to the respective innovation-based environmentally-benign manufacturing scores.

2. MODELING OF ENVIRONMENTALLY-BENIGN MANUFACTURING

Following assumptions have been made during the present modeling [14,15]:

- Model has been restricted to industries belonging to the same sector
- Organizations must have come up with at least one innovation and must be the recipient of all the innovations
- Adoption time &adoption cost for innovative technologies for all the organizations must be considered
- Adoption cost of the innovation includes fixed cost and life-cycle assessment cost
- Sustainability index of the industries must be determined based on the various indicators and variables

The modeling morphology used in the present research work is as follows:

- Consideration of a case-study of innovation-driven pollution control equipment used by different industries
- Evaluation of the preliminary status of the environmentally-benign manufacturing in the participating organizations (mapping of innovations created & adopted)
- Determination of the costs and the time associated with the creation &adoption of the innovations
- Selection& classification of the components along with their underlying sustainability indicators and variables
- Computation of the average environmentally-benign manufacturing index based on the weighted average technique
- Evaluation of the relative innovation-driven environmentally-benign manufacturing indices and ranking the industries based on the scores

A case study of four leading steel industries having six innovations in the area of air pollution control has been considered. The innovations are bag filters, scrubbers, electrostatic precipitators with outlet emissions as 250, 150 & 125 mg/Nm^3 and less-energy intensive electrostatic precipitator with outlet emission as 250 mg/Nm^3. Table 1 presents the details of the innovations executed and implemented by the steel industries.

Table 1: Innovations Executed & Implemented by the Steel Industries

Steel Companies	Innovations Implemented	Node Number	Branches Generated	Branches Terminated
A	Bag filters	I	1	2 & 3
B	Scrubbers Electrostatic precipitators with outlet emission as 150 & 125 mg/Nm^3	II	2, 5 & 6	Nil
C	Less energy intensive electrostatic precipitators with outlet emission as 250 mg/Nm^3	III	3	4 & 5
D	Electrostatic precipitators with outlet emission as 250 mg/Nm^3	IV	4	1 & 6

The adoption time of innovations by various industries along with the normalized data is shown in Table 2. The normalized adoption times have been determined using equation (1). Every organization has costs associated with the creation and adoption of innovative technology, as well as, with the implementation of the innovations by recipient organizations. The two major components of these costs are initial costs and life-cycle assessment costs. Table 3shows the individual estimated costs values of different technologies along with the normalized values, which are obtained by taking the ratio of individual cost element to the sum total of all the cost elements.

$$AT_{jk} = (1-t_{jk}/t_{max}) \quad (1)$$

where,

AT_{jk} = normalized adoption time to adopt j^{th} innovations by k^{th} organization

t_{jk} = time taken to adopt j^{th} innovations by k^{th} organization

t_{max} = estimated time till all organizations have adopted relevant technology

Table 2: Time Data for Adoption of Innovations

Innovations	Max. Adoption Time in Months	Actual & Normalized Adoption Time (Months)			
		A	B	C	D
1	15	0 (1.00)	15 (0.00)	10 (0.33)	12 (0.20)
2	8	5 (0.38)	0 (1.00)	8 (0.00)	7 (0.13)
3	10	4 (0.60)	10 (0.00)	0 (1.00)	5 (0.50)
4	12	3 (0.75)	2 (0.83)	12 (0.00)	0 (1.00)
5	14	10 (0.29)	0 (1.00)	4 (0.72)	14 (0.00)
6	11	9 (0.18)	0 (1.00)	5 (0.55)	11 (0.00)

Table 3: Cost Data for Adoption of Innovations

Innovations	Actual & Normalized Adoption Cost (Lakh)			
	A	B	C	D
1	40 (0.0119)	55 (0.0164)	50 (0.0149)	65 (0.0194)
2	35 (0.0104)	30 (0.0089)	50 (0.0149)	40 (0.0119)
3	160 (0.0477)	165 (0.0492)	150 (0.0447)	180 (0.0537)
4	110 (0.0328)	105 (0.0313)	120 (0.0358)	100 (0.0298)
5	240 (0.0715)	210 (0.0626)	215 (0.0641)	235 (0.0700)
6	255 (0.0760)	240 (0.0715)	245 (0.0730)	260 (0.0775)

The present analysis has been performed considering 4 core components, 10 indicators and 26 variables, which were chosen through an extensive literature review, assessment of the available data and consultation with the practicing engineers and the Agenda 21 proposed by the UNEP [16-18]. The indicators track; whether the current industrial activities of the organization, threaten the way-of-life for future generations, influence major investment decisions & consumer purchases, help industries make progress towards sustainable development. The environmentally-benign sustainability index is mathematically evaluated as an equally weighted average of all the above indicators, which may be measured and analyzed by issue-by-issue basis methodology as shown in figure1. The average sustainability index of different organizations is basically an estimated score of the relevant modules for adopting the new innovations by the innovator and recipient organizations.

Table 4 shows the average score and the relative importance (weights) obtained by various indicators of environmentally-benign manufacturing. The scores have been assigned based on various variables under a particular indicator and their importance with respect to the sustainability status, as per the discussion with practicing engineers. The average sustainable manufacturing index for each innovation has been obtained by taking the weighted average of all the scores obtained by the various indicators for particular innovation. The weights are the relative importance rating assigned to each indicator.

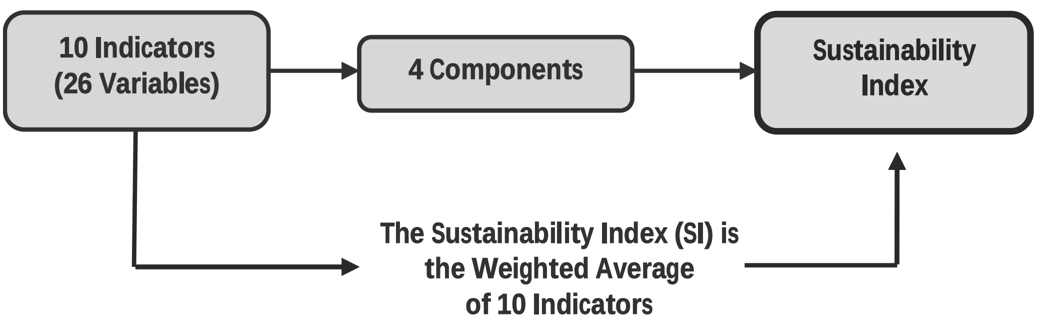

Fig.1: Evaluating the Sustainability Index

Table 4: Relative Weights and Average Sustainability Score of the Indicators

Components	Logic for Selection	Indicators and Variables	Rel. Wt.	Indicator Average Scores					
				I-1	I-2	I-3	I-4	I-5	I-6
Environmental Systems	Vital environmental systems are maintained at healthy and improved levels	**1. Ambient Air Quality** 1. Particulate Concentration 2. NO_2 Emission & Conc. 3. SO_2 Emission & Conc. 4. CO_2Emission& Conc. 5. Hydrofluorocarbons Emission	****	0.6	0.5	0.65	0.65	0.7	0.85
Environmental Stresses	Effects on the levels of anthropogenic stress are low enough to engender no demonstrable harm to environmental systems	**2. Bio Diversity** 6. Eco - regions at Risks 7. Threatened Birds 8. Threatened Mammals	*	0.65	0.6	0.7	0.7	0.75	0.8
		3. Eco-System Stresses 9. Acidification & Corrosion	**	0.3	0.3	0.65	0.65	0.75	0.85
		4. Wastes & Consupt. Pattern 10. Hazardous Waste Generation	*	0.3	0.3	0.45	0.45	0.5	0.5
Human Vulnerability	Effects on the people and social systems are not vulnerable to environmental disturbances affecting their basic wellbeing	**5. Human Health** 11. Intestinal Infectious Diseases 12. Respiratory Infections 13. Life Expectancy 14. Mortality Rate	****	0.5	0.55	0.7	0.7	0.8	0.9
		6. Natural Disaster Vulnerability 15. Environmental Disasters 16. Hazard Exposure	*	0.7	0.7	0.5	0.5	0.5	0.5
Social & Institutional Capacity	It has in place institutions and underlying social patterns of skills, attitudes and networks that foster effective responses to environmental challenges	**7. Environmental Governance** 17. Agenda 21 Initiatives 18. Rule of Law 19. Civil Liberties	**	0.6	0.55	0.75	0.7	0.8	0.85
		8. Energy-Efficiency 20. Energy Consumption 21. Renewable Energy Production	***	0.8	0.8	0.95	0.75	0.7	0.65
		9. Private Sector Responsiveness 22. Corporate Sustainability 23. ISO 14001 Certified Companies 24. Private Sector Environmental Innovations	**	0.35	0.3	0.65	0.6	0.7	0.8
		10. Science & Technology 25. Innovation Capacity 26. Research scientists	***	0.6	0.55	0.95	0.8	0.85	0.7
Sum			23	12.8	12.2	16.9	15.6	16.9	18.5
Average Sustainability Index (W_i)				0.55	0.53	0.73	0.68	0.74	0.80

Table 5 shows the innovation-driven environmentally-benign manufacturing scores, which are obtained by taking the sum of product of 'W_i' and 'X_i' for each individual organization. Thus, for example, the innovation-driven environmentally-benign manufacturing score of the organization 'A' is found to be 34.07%. The 'X_i' values are obtained as the ratio of normalized adoption time to normalized adoption cost elements for each innovation by 'i^{th}' individual organization. Finally, the relative innovation-driven environmentally-benign manufacturing scores on percentage basis have been calculated, which have been utilized to evaluate the sustainability of various organizations.

Table 5: Innovation-Driven Environmentally-Benign Manufacturing Scores

Innovations	Average Sustainability Index (W_i)	Company A		Company B		Company C		Company D	
		X_A	$W * X_A$	X_B	$W * X_B$	X_C	$W * X_C$	X_D	$W * X_D$
1	0.554	84.03	46.55	0.00	0.00	22.14	12.26	10.30	5.70
2	0.528	36.05	19.03	112.35	59.32	0.00	0.000	10.50	5.54
3	0.733	12.58	9.22	0.00	0.000	22.37	16.39	9.31	6.82
4	0.678	22.86	15.49	26.51	17.97	0.00	0.000	33.55	22.74
5	0.735	3.99	2.93	15.98	11.74	11.23	8. 25	0.00	0.000
6	0.802	2.36	1.89	13.98	11.21	7.53	6.03	0.00	0.000
Total Score		95.11		100.24		42.93		40.80	
% Score		**34.07**		**35.91**		**15.38**		**14.61**	
Ranks		**II**		**I**		**III**		**IV**	

3. CONCLUSIONS

The innovation-driven environmentally-benign manufacturing scores obtained by various organizations depend upon the average sustainability index and normalized adoption time-to-cost ratio for different innovations. The average sustainability index has been obtained based on various core components and their underlying indicators, which directly or indirectly influence the sustainable behavior of the organization. The weighted average method was used to evaluate the sustainability index of various organizations for different innovations. The innovation-driven environmentally-benign manufacturing scores for different organizations have been obtained by taking the mean of the sum of the product of time-cost ratio and average sustainable manufacturing index, respectively. The organization 'B' has the highest sustainable manufacturing score followed by the organization 'A' and then the rest. These ranks are of immense importance, because they give preliminary idea about performances of implemented sustainable manufacturing practices based on various innovations carried and adopted by relevant units.

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