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An Optimization Model for Sustainability Program

N. Jawahar[1] · **G. Satish Pandian**[2] ·
Angappa Gunasekaran[3] · **Nachiappan Subramanian**[4]

Abstract A sustainability program is about implementing essential sustainability practices at various intensities that will not harm people because of firm actions. This paper formulates an optimization model to identify an optimal intensity of implementation of selected sustainability practices referred as sustainability program for maximising manufacturing industry sustainability performance for a known set of budgetary and minimum thresholds constraints with respect to economic, social and socio-economic criteria. Besides modelling the paper proposes a random search procedure embedding the NN to determine the optimal sustainability program and explains the usefulness with a sample problem. Sensitivity analysis is carried out to understand the behaviour of the model. It is observed that the sustainability performances depend on the constraints such as budget limitation and threshold values of performance criterion.

Keywords Sustainability program · Neural network · Sustainability performance and optimization

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✉ Nachiappan Subramanian
nachiappan.subramanian@nottingham.edu.cn

N. Jawahar
jawahartce@yahoo.co.uk

G. Satish Pandian
gspmech@gmail.com

Angappa Gunasekaran
agunasekaran@umassd.edu

[1] Thiagarajar College of Engineering, Madurai 625 015, India

[2] Department of Mechanical Engineering, Thiagarajar College of Engineering, Madurai 625 015, India

[3] Department of Decision and Information Sciences, Charlton College of Business, University of Massachusetts, North Dartmouth, MA 02747-2300, USA

[4] Nottingham University Business School, Ningbo 315100, China

Symbols

B	Budget
CPI	Composite Performance Index
E	Economic performance in percentage
it_{max}	Maximum iteration
LR	Learning rate
MSE	Mean square error
N	Number of neurons
S	Social performance in percentage
SE	Socio-economic performance in percentage
Z	Overall performance score
Z_{opt}	Optimal performance

Parameters

B_{max}	Maximum budgetary limit
CPI_j	Composite Performance Index (industry wise)
CPI_j^A	CPI score of jth industry derived with MADM approach
CPI_j^E	CPI score of jth industry predicted through NN Model
C_{m_p}	Operational cost of pth sustainable practice to its mode m
$E_{\min}$	Minimum threshold of economic performance in percentage
i	Performance dimension
I	Number of performance dimensions
it	Initial iteration
j	Industry identifier (alternative)
J	No. of industries
m	Modes
M	Number of modes
p	Practices
P	Number of practices
PWP_{ij}^A	Actual percent weighted performance ith dimension of jth industry
PWP_{ij}^E	Estimated percent weighted performance ith dimension of jth industry
$SE_{\min}$	Minimum threshold of socio-economic performance in percentage
S_i^k	Performance score for ith dimension to its kth level
$S_{m_p}^i$	Performance scores for sustainable program,
S_j^i	Performance score for jth industry to ith dimension
$S_{\min}$	Minimum threshold of social performance in percentage
W_i	Weights of criterion
$X_{m_p}^{Opt}$	Optimal sustainable program

Decision variable

X_{m_p}	Binary variable

1 Introduction

Sustainable manufacturing involves the use of sustainable processes and systems to produce sustainable products and it is recently recognised as an important activity in the manufacturing industry (Faulkner and Badurdeen 2014). Roberts and Ball (2014) define environmental technologies in terms of production equipment, methods and procedures that are available to deal with sustainability that aim to conserve energy as well as natural resources and to minimize environmental impact because of human activities. Sustainability in industries is achieved through implementing practices that includes techniques such as technologies, equipment, operating procedures and management orientation approaches such as product design, manufacturing, environmental management, technology choice and design of industrial systems. A sustainability program is a set of essential sustainability practices that are implemented at various intensities from minimum level to maximum level to achieve the desired performances is referred as modes in this paper. Sustainability practices are classified into three major categories to address the underlying triple bottom line performances of industries such as Manufacturing Innovation Practices (MIP), Environmental Management Regulation Systems (ERMS) and Societal Welfare Schemes (SWS) (Rho et al. 2001; Singh et al. 2006). Sezen and Cankaya (2013) stated that sustainability issues are swiftly emerging as one of the most important aspects in organisation and influences strategic decision making such as business management, manufacturing, and product development. The achievement of sustainability depends on sustainability program and varies significantly with respect to the sustainable practice implementation decisions, which can be carried out with different intensity levels referred as modes in this paper (i.e. levels). However, industries struggle to understand what practices they need to select for implementation and what level or intensity they need to concentrate to achieve the set performances. This is the major gap in the literature and it would be helpful for the industries if they know their concentration level of selected practices to achieve the desired performance. Whatever be the sustainability program, it requires the ways to measure how well a community is meeting the needs and expectations of its present and future members. Linke et al. (2013) highlighted in their study that a sustainable indicator may be defined “as a measure or an aggregation of measures from which conclusions on the phenomenon of interest can be inferred”. Sustainability indicators need to capture all three dimensions of sustainability at various levels within organisation with respect to, facilities, processes, and products. The measures of sustainability are normally referred in three dimensions such as economic, environmental and social. We measure effect of environmental practices in terms of socio-economic measures and our three dimension indicators are economic (E), social (S) and socio-economic (SE) Economic performance aims to fulfil the current needs, the one that is needed for the survival of any business. The demand for social performance arises to meet the equitable standard of living. The socio-economic dimensions are meant to take care of future livings.

Besides, the industries need to meet a minimum level of performance or threshold with respect to economic, social and socio-economic dimensions. Hence industries are keen to know to what extent they need to implement practices to achieve the desired economic, social and socio-economic performances targets.

The above discussions reveal that sustainability program to be effective in manufacturing industry need to address the following questions (1) What would be appropriate intensity level to implement the selected practices to achieve the desired economic, social and socio-economic dimensions of sustainability performance? and (2) how to estimate the relationships between the practices and performances? This paper offers solution to identify an optimal sustainability program (i.e. practice mode combination set: Each mode ‘m’ of practice ‘p’ that contributes to three dimensions of sustainability performance) for maximum sustainability performance under the budgetary and threshold performance constraints. Sustainable practices at higher operating modes can be achieved with the performance greater than threshold levels with significant upfront additional investment. Generally, budget is the major concern and constraint for any program. When the budget towards sustainable practice implementation becomes a constraint to any sector/industry, then there arises the problem of choosing a specific combination of mode of practices for maximum sustainable performance by satisfying specific criteria threshold values. This necessitates the industry to identify and implement specific mode of sustainable practices to optimise the required sustainability performances. On this concern, this paper formulates an optimization model to identify an optimal sustainability program to maximise manufacturing industry sustainability performance under the limitation on budgetary and minimum thresholds on economic, social and socio-economic criteria. Besides model formulations, a neural network optimization approach is proposed to obtain the optimal solution. The rest of the paper is organized as follows: Sect. 2 reviews the literature on sustainability models; Sect. 3 delineates the model formulation, problem statement and mathematical model; Sect. 4 discusses the proposed methodology with illustration; performance study is addressed in Sect. 5 and finally Sect. 6 concludes with the summary of the contributions and future research directions for overcoming the limitations of the model and solution methodology.

2 Review of sustainable optimization models and methods

Sustainable optimization models appeared in early twentieth century mainly concentrated on economic and environmental aspects (Nahorski and Ravn 2000). Jayal et al. (2010) reviewed the development of sustainable products, processes and systems, and stated that achieving sustainability in manufacturing requires a holistic view spanning not just the product, and the manufacturing processes involved in its fabrication, but also the entire supply chain, including the manufacturing systems across multiple product life-cycles. Florez and Castro-Lacouture (2013) have developed a mixed integer optimization model for the sustainable materials selection using objective and subjective factors. Design, budget, and the number of points achieved under the leadership in energy and environmental design (LEED) account for objective factors while subjective factors comprehend user-based perceptions. Florez and Castro-Lacouture (2013) have studied the influence of objective and subjective factors with two cases using the optimization model proposed. Alshamrani et al. (2014) presented an integrated life cycle assessment (LCA)—LEED model and assigned corresponding LEED scores to get a high level of sustainability assessment, for the structure and envelope systems of buildings.

Sustainable management requires careful considerations of environmental sustainability, economic sustainability and corporate social responsibility (CSR) related issues. Choi (2014) formulate an optimization model to address the sustainability related issues. Choi (2014) considered the number of accidents with a quantity dependent distribution parameter and formulated the objective function by incorporating analytical constraints which relate to environmental sustainability and CSR in to the model to obtain global optimal solution. López-Villarreal et al. (2014) proposed a mathematical programming model for the pollution trading among different pollution sources which considers the sustainability of surrounding watershed. The formulation involved the minimization of costs associated to the implementation of required technology in order to achieve optimal water quality conditions. The formulation was applied to a case study involving the drainage system of the Bahr El- Baqar region in Egypt; the results show the advantages of the proposed approach in terms of cost and sustainability. The review reveals that optimization model have been applied to several applications and the concept is gradually spreading across the product, process and its entire supply chain especially in the manufacturing context. Prior studies used mixed integer programming approach with objective and subjective factors to select sustainable materials. However it is obvious from the previous studies that there is no specific optimization model to choose a suitable intensity of mode of sustainable practices to achieve desired set of performances.

Multi-criteria decision making approach is widely used methodology for sustainability modelling and analysis. Chan and Tong (2007) presented a grey relation analysis including environmental factor, besides technical and economic factors to rank the materials for selection. Bouchery et al. (2012) proposed an inventory model, with one of the objective to control carbon emissions, by sustainable procurement through optimal order quantity model. The model with the set of efficient solutions (pareto optimal solutions) is analytically characterized. They proposed the interactive procedure as a new combination of multi-criteria decision analysis techniques. Govindan et al. (2014) proposed a sustainability integrated multi-objective optimization model in decision-making, for a perishable food supply chain network (SCN). The goal of the proposed integrated model, two echelon location-routing problem with time-windows (2E-LRPTW), was to determine the location and number of facilities and to optimize the amount of products delivered to lower stages and routes at all levels. They also aimed to reduce costs caused by carbon foot print and greenhouse gas emissions throughout the network. The proposed method included a novel multi-objective hybrid approach called MHPV, a hybrid of two known multi-objective algorithms. MHPV features two strategies for leader selection procedures (LSP), and crowding distance is compared to common genetic algorithms based on meta-heuristics. Finally they indicate that the hybrid approach achieves better solutions compared to others. Zhang et al. (2014) have considered economic, social and environmental factors, as three aspects of sustainability and proposed a multi-objective optimization to quantify sustainability performance of supply chain. From the methods point of view most of the sustainable studies concentrate on optimizing the eco-rival parameters to either minimize environmental hazardous waste or save scarce resources (i.e. preservation of scarce resources for the use of future needs) for minimum environmental effects. Prior studies considered grey techniques and genetic algorithms to solve non-linear multi-objective models. However, it is very hard to find a method to identify a relationship between intensity of practices and different dimensions of sustainability performances.

On this concern, this paper presents an analytical model to derive and maximize the sustainability performance through the relationship established with neural network.

3 Model formulation

Sustainability performance depends on sustainability program consideration and implementation. Based, on the extensive review from the previous studies that widely considered major sustainability elements relating to ‘Sustainable Manufacturing’ and the discussions with the leading practitioners the following six sustainable practices were identified as the contributors of sustainability programs (Klassen and McLaughlin’s 1996; Singh et al. 2006; Montabon et al. 2007; Delmas 2001; Curkovic 2003; Yang et al. 2010; Jayal et al. 2010; Pandian et al. 2013b).

- Training on environmental practices to employees: success of any new initiative needs training, which plays a major role in its adaptation. Besides, it has to be given several times depending upon the knowledge level of employees.

- Environmental management systems—variety of EMS systems are available for use. Each practice has unique features and impacts differently on the sustainable performances. The process and product characteristics influence the selection of EMS.
- Environmental performance audit—any implementations needs continuous monitoring for betterment and improvement. The auditing is the one which materialize the continuous improvement model.
- Research and development—it is the foundation for business sustainability, earlier considered for as a contributor for economic growth. Now it is recognised as mandatory for environmental and climate change concerns.
- R&D investment—it is a dimension that exposes the interest of the industry on the society.
- Quality and management practices—systematic practices leads to higher efficacy. Every practice has its own merits and limitations. Industries would experience different performances under different practice-modes, which depends on their nature of products and services.

The literature addresses number of practices such as managerial, sustainable, and environmental, and so on. Table 1 presents the six practices (p) that are identified based on the rationalization and can contribute significantly to any of the sustainability performance dimensions such as economic, social and socio-economic. In general, these practices are carried out either at five different levels or falls under five groups as addressed as “modes” (m) in Table 1. It is assumed that the cost of operating a practice ‘p’ at its mth mode ‘C_{m_p}’ is known (from past experiences and estimations) for all p and m.

The aim of the paper is to develop a model to select a best and acceptable sustainability program evaluated in terms of economic, social and socio-economic performance dimensions (criteria) under budget limitations and other constraints. Table 2 shows the twelve dimensions (sub criteria), four each for economic, social and socio-economic performance dimensions (criteria), identified for evaluating the sustainability, giving importance to all the sub criteria.

There are more practices such as managerial, sustainable, environmental and so on which are implemented in the firms to improve sustainability performance. However, all the practices cannot be included in our study as it diverts the focus of the study . Hence, we have associated them into six groups (6) as shown in Table 1. Furthermore, the mode of practice is distributed into five point (5) Likert scale as it is widely used in many articles and gives appropriate number of options to choose for respondents than any other options such as bi-optional, three, seven or nine point Likert scales.

Sustainability stands on three dimensions such as economic, social and socio-economic performances, however its contribution may vary with respect to the nature (based on the impact of industries like Chemical manufactures, vehicle Assembly etc) of the industry. With respect to this model, three performance dimensions are considered equal irrespective of the sector of study.

Each mode ‘m’ of practice ‘p’ contributes to every sustainable performance dimension ($i = 1-12$). Figure 1 shows the architecture of the inter-relationship between the practice ‘p’, optional mode ‘m’ and performance dimension ‘i’.

The performance contribution by mth mode of practice p to the ith dimension is addressed here as $S^i_{m_p}$. Let binary variable ‘X_{m_p}’ (0 or 1) denote the selection of mode ‘m’ for practice ‘p’ and S^i represents the sustainable performance of dimension ‘i’ to any sustainability program ‘X_{m_p}’ (practice-mode combination set). Hence, S^i can be determined using the relationship given in Eq. 1.

Table 1 Sustainable practices

Practice (p)	Reference dimension	Rationalization	Mode (m)				
			1	2	3	4	5
Training on sustainable practices to employees (1)	Social and economical	Criterion that recognises the adoption of environmental and management practices towards sustainable in present and future	Yearly	Half yearly	Quarterly	Bimonthly	Monthly
Frequency of environmental practices audit (2)	Environmental	Criterion that monitors the effectiveness in the implementation of environment practices	Yearly	Half yearly	Quarterly	Bimonthly	Monthly
Environmental management system (3)	Environmental	Criterion that protects the environment from pollution and hazards	Nil	Green manufacturing	Cleaner production	In campus ETP/STP plants	ISO 14000
Proportion of employees involved in R&D activities (4)	Social and economical	Criterion that takes care of future needs of the society and as well their survival	$\leq$1 %	1–5 %	6–15 %	16–30 %	$\geq$30 %
Proportion of Expenses from turn over for R&D activities (5)	Social and economical	Criterion that states the survival probability in the business	$\leq$0 %	1–5 %	6–20 %	21–50 %	$\geq$50 %
Quality/management (6) practices	Environmental and economical	Criterion that directs towards excellence	Six sigma	Product chart	EOQ	Zero defect	Eco friendly

Table 2 Dimensions that influence sustainable performance

Goal criteria	Sustainable performance dimension (i)		
	Economic (1–4)	Social (5–8)	Socio-economic (9–12)
Sub-criteria	Income/profit	Increase in literacy rate	Increase in per capita income
	Production	Drop in accidental rate	Improved transport and communication facilities
	Turn over	Fall in crime rate	Regularity of the employee
	Return on investment	Decline in patient admissions in hospitals	High unity and morale of the employees

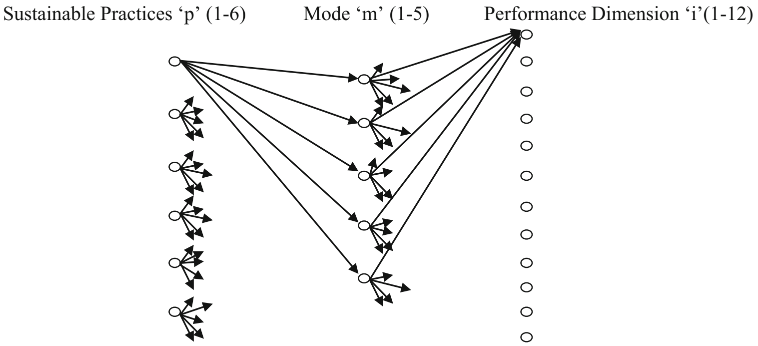

Fig. 1 Inter-relationship between p–m–i

$$S^i = \sum_{p=1}^{6}\sum_{m=1}^{5} S^i_{m_p} \times X_{m_p} \tag{1}$$

The summation of all performance scores indicates the overall sustainable performance of the combination of the modes selected for implementation. Equation 2 provides the overall performance score ‘Z’ for a sustainability program. The objective of the model thus becomes maximization of Z.

$$Z = \sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=1}^{12} S^i_{m_p} \times X_{m_p} \tag{2}$$

The model assumes that only one mode is chosen to each practice. The constraint Eq. 3 takes care of this limitation.

$$\sum_{m=1}^{5} X_{m_p} = 1 \quad (\forall p = 1 \text{ to } 6) \tag{3}$$

Besides, industry is constrained with budgetary limit of ‘$B_{\max}$’ for implementing sustainable practice. This limit on budget is protected with Eq. 4.

$$\sum_{p=1}^{6}\sum_{m=1}^{5} C_{m_p} \times X_{m_p} \leq B_{max} \tag{4}$$

In addition to this, the model is formulated with certain minimum threshold/target values on each of the economic ‘$\mathrm{E}_{\mathrm{min}}$’, social ‘$\mathrm{S}_{\mathrm{min}}$’ and socio-economic ‘$\mathrm{SE}_{\mathrm{min}}$’ performances. The threshold values depend on manufacturers’ target on return on investment, depends on societal pressure, company policies and government regulations etc. It varies region wise and is decided by the manufacturer. Equations 5–7 administer the above conditions.

$$\sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=1}^{4} S^{i}_{m_p} \times X_{m_p} \geq E_{min} \tag{5}$$

$$\sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=5}^{8} S^{i}_{m_p} \times X_{m_p} \geq S_{min} \tag{6}$$

$$\sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=9}^{12} S^{i}_{m_p} \times X_{m_p} \geq SE_{min} \tag{7}$$

The decisions of implementing the mode ‘m’ at practice ‘p’ (i.e.X_{m_p}) influence the objective function (Eq. 2) and constraints (Eqs. 3–7). Hence X_{m_p} $(\forall p = 1{-}6, \forall m = 1{-}5)$ become the decision variables to the model.

3.1 Statement of the problem

Determination of optimal sustainability program $X^{Opt}_{m_p}$ $(\forall p = 1{-}6, \forall m = 1{-}5)$ for maximum sustainable performance (Z) under limited budget for sustainable practice ‘B_{max}’ while meeting the minimum threshold values on economic ‘$\mathrm{E}_{\mathrm{min}}$’, social ‘$\mathrm{S}_{\mathrm{min}}$’ and social-economic ‘$\mathrm{SE}_{\mathrm{min}}$’ performances, given the cost of implementation ‘C_{m_p}’ $\forall p = 1{-}6, m = 1{-}5$.

3.2 Mathematical formulation

The mathematical model developed to evolve sustainable program for maximum performance (Eq. 8) under the operational practice (Eq. 9), budgetary limitation (Eq. 10), and performance threshold constraints (Eqs. 11–13) are as follows:

$$\mathrm{Max}\, Z = \sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=1}^{12} S^{i}_{m_p} \times X_{m_p} \quad (\textit{Sustainable performance}) \tag{8}$$

Subject to,

$$\sum_{m=1}^{5} X_{m_p} = 1 \quad (\forall p = 1 \text{ to } 6) \quad (\textit{One mode for one practice}) \tag{9}$$

$$\sum_{p=1}^{6}\sum_{m=1}^{5} C_{m_p} \times X_{m_p} \leq B_{max} \quad (\textit{Budget limitation}) \tag{10}$$

$$\sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=1}^{4} S^{i}_{m_p} \times X_{m_p} \geq \mathrm{E}_{\mathrm{min}} \quad (\textit{Economic performance target}) \tag{11}$$

$$\sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=5}^{8} S_{m_p}^{i} \times X_{m_p} \geq S_{\min} \quad (\textit{Social performance target}) \tag{12}$$

$$\sum_{p=1}^{6}\sum_{m=1}^{5}\sum_{i=9}^{12} S_{m_p}^{i} \times X_{m_p} \geq SE_{\min} \quad (\textit{Socio-economic performance target}) \tag{13}$$

$$X_{m_p} \in [0, 1] \tag{14}$$

$$X_{m_p} \text{is an integer} \quad (\forall p = 1\text{–}6, \forall m = 1\text{–}5) \tag{15}$$

Constraints 14 and 15 restrict X_{m_p} as a binary variable.

4 Proposed methodology

The performance scores, $S_{m_p}^{i}$ ($\forall p = 1$–$6, \forall m = 1$–5 and $\forall i = 1$–12) are not discrete values and depend on combination of practice-mode set X_{m_p} ($\forall p = 1$–$6, \forall m = 1$–5), which is the decision variable to the formulation. There is no mathematical expression between $S_{m_p}^{i}$ and X_{m_p}. Taking the discrete factors of the problem into consideration, it is clear that it is not possible for developing a precise mathematical model for eliciting the relationships. This limits the application of any analytical approach to solve this model. However, the performance scores $S_{m_p}^{i}$ can be predicted with the responses for the twelve performance criteria to the set of practice-mode combination 'X_{m_p}' ($\forall p = 1$–$6, \forall m = 1$–5) through the questionnaire survey. Numerous studies have adopted neural network (NN) approach for the prediction or for any other purposes intended for the results irrespective of the study area. It can be taken into consideration that the NN application of prediction is used widely. Meanwhile, another approach is required to identify such hidden patterns. Owing to such intricacy, the proposed model should have classification and prediction capabilities, which make artificial neural network (ANN) an appropriate technique to develop expert systems and it is now commonly used in the literature (Rouhani and Ravasan 2013). On this consideration, this paper proposes a NN approach for estimation of $S_{m_p}^{i}$. Hence, a random search procedure (RSP) embedding the NN is proposed to find the optimal sustainability program. Figure 2 shows the structure of the proposed RSP. The various modules of it are illustrated in the following sections. The model is created in MATLAB (version 10a) software.

4.1 Input module

The following data governing/influencing the decision on sustainable practice implementations are given as input: B_{max}, E_{min}, S_{min}, SE_{min} and C_{m_p} ($\forall$p = 1–6, $\forall$m = 1–5).The data used for the illustration purpose are: B_{max} = Indian Rupee (INR) 30 lakhs (1US ≈ INR60), $E_{\min} = 12$; $S_{min} = 6$; and $SE_{min} = 9$; C_{m_p} as given in Table 3.

4.2 Parameter initialisation module

The initial iteration count 'it', the counter '$\text{it}_{\max}$' that fix the number of evaluations to be carried out before termination and the optimal performance value parameter 'Z_{Opt}' are set as 1, 1000 and 0 respectively.

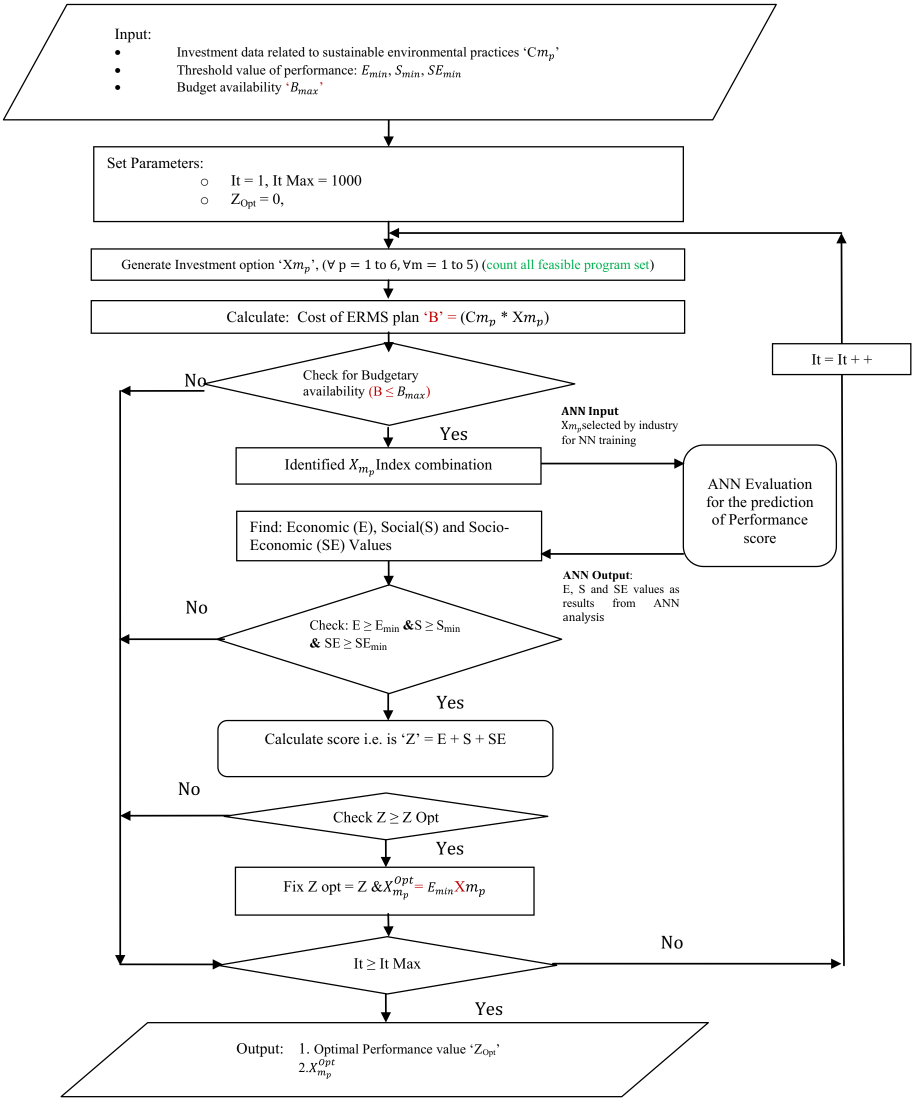

Fig. 2 Structure of the proposed random search procedure

Table 3 Sustainable practices operational cost matrix Cm_p (in 100,000 INR)

P	M				
	1	2	3	4	5
1	2	4	3	7	9
2	4	3	4	5	5
3	3	7	6	6	8
4	1	5	3	8	7
5	2	2	5	9	4
6	4	1	3	4	8

Table 4 Sustainability program ‘Xm_p’

P	M				
	1	2	3	4	5
1	0	0	0	0	1
2	0	0	0	1	0
3	1	0	0	0	0
4	0	0	0	0	1
5	0	1	0	0	0
6	0	0	1	0	0

4.3 Generation of sustainability program module

The sustainability program X_{m_p}, ($\forall$p = 1 to 6, $\forall$m = 1–5), satisfying one mode for one practice, are randomly generated as a matrix with binary code. Table 4 shows the sustainability program matrix X_{m_p} generated randomly in the first iteration.

4.4 Budget estimation and checking module

This module estimates the budget ‘B’ towards implementing sustainability program ‘X_{m_p}’ under evaluation, (indexed as ‘X_{m_p}’ $= X_{5_1} = 1, X_{4_2} = 1, X_{1_3} = 1, X_{5_4} = 1, X_{2_5} = 1$ and $X_{3_6} = 1$) using the relation given in Eq. 16

$$B = \sum_{p=1}^{6} \sum_{m=1}^{5} C_{m_p} \times X_{m_p} \tag{16}$$

Then the estimated budget is checked with the budget limit B$_{max}$, to find whether the randomly generated plan is feasible or not. If feasible (i.e. B $\leq$ B$_{max}$), then it proceeds to evaluation module. Otherwise, it is diverted to algorithm termination check module. The estimated budget corresponding to plan is found as INR 29,00,000 and hence the algorithm proceeds to evaluation model.

4.5 Evaluation module

The evaluation parameters of any budgetary feasible sustainability program are the performances with respect to economic, social and socio-economic dimensions. A neural network (NN) model, a sustainable performance estimator, developed to provide them. This module briefly describes first the NN model development process and subsequently how the performances to the given sustainability program are derived using the NN model is explained.

4.5.1 Neural network model

This section presents the NN model developed for the estimation of individual sustainable performance to the any sustainability program of an industry. The capacity to generalize is the key property of neural networks. This is how neural networks take care of the inputs which have not been learned but which are similar to inputs seen during the training phase. Generalization can be seen as a way of reckoning from a number of examples to the general case. This type of reasoning is not suitable in a logical context but can be observed in human behavior (Ding et al. 2014). The proposed back propagation algorithm is used to train the weights of the feed-forward neural (FNN) network as the back propagation algorithm is strong towards local searching ability (Sarangi et al. 2013). The Sect. 4.5.1.1–4.5.1.3 delineate the data, architecture and optimization of the NN network respectively.

4.5.1.1 NN data The input and output data that are required (1) to train NN, (2) to determine the optimal number of neurons in the hidden layer, and (3) to test the validity of the NN have been obtained through the survey instrument (questionnaire) is given in Appendix (Pandian et al. 2013b). The input data for the NN is collected from the responses provided in the Table 16 of the questionnaire, which provides the code (1–5) for each mode 'm' to all the practices 'p'. The Output data for NN is derived by applying multi attribute decision making (MADM) approach (Pandian et al. 2013a) based on the performance level 'k' indicated by the respondents to each performance dimension 'i' in Tables 17, 18, 19 of the same questionnaire in appendix and relative weights which is used for the estimation of composite performance index for industrial sustainability. One of the most vital steps in the application of any MADM is the precise judgment of the criterion weight. It is decisive in methods where there is a need to draw out qualitative information from the decision maker. Very often qualitative data cannot be known in terms of absolute values. Consequently, many decision making methods attempt to determine the relative importance, or weight of the alternatives in terms of each criterion involved in the problem (Triantaphyllou and Mann 1995). The required output data for NN are estimated by applying MADM technique, with the aid of the weights to all the dimenionions of sustainability. The AHP based pair wise comparison method which is proposed by Saaty (1980) has long attracted the interest of many researchers. The factor prioritisation influences decision making and it can be dealt with AHP approach (MADM technique), which is suitable for both qualitative and quantitative analysis (Subramanian et al. 2014). Configuration of objective by using recognized indicators to achieve the sustainability performance dimension is a demanding task and in addition, it becomes more complicated when it is measured on various dimensions and converted into a single value (Kuik and Gilbert 1999). However, the qualitative information requires some sort of conversion into quantitative scores to evolve any meaningful insights. The performance score $\mathrm{S}_{\mathrm{i}}^{\mathrm{k}}$ for ith dimension to its kth level is valued in the range 1–5. Supposing that $\mathrm{S}_{\mathrm{j}}^{\mathrm{i}}$ indicates the performance score obtained by the jth industry to the ith dimension, then the Composite sustainability performance index of the jth industry ($\mathrm{CPI}_{\mathrm{j}}$) is estimated in the scale of 1–100 using the relationship given in Eq. 17.

$$\mathrm{CPI}_{\mathrm{j}} = 20 \times \sum \left(\mathrm{W}_{\mathrm{i}} \times \mathrm{S}_{\mathrm{j}}^{\mathrm{i}}\right) \tag{17}$$

As the judgements by the respondent are in the scale of 1 to 5, the requisite percentile CPI score '$\mathrm{CPI}_{\mathrm{j}}$' for an industry is derived only when the weighted scores ($\mathrm{W}_{\mathrm{i}} \times \mathrm{S}_{\mathrm{j}}^{\mathrm{i}}$) are multiplied by 20 to get resultant CPI index. Composite sustainable performance ($\mathrm{CPI}_{\mathrm{j}}$) index using the above Eq. 17 is found out for a single manufacturing firm by providing each performance dimension, its identifier, appropriate weights and the responses are given in Table 5. Table 6 displays the sample input and derived output data set of 120 responses of Indian Manufacturing Industries

Table 6 displays the sample input and derived output data set of 120 responses of Indian manufacturing firms.

4.5.1.2 NN architecture The architecture of NN has been modelled with six neurons, one each for each sustainable practice, as input layer, 12 output neurons matching to individual scores of each sustainable performance dimension as output layer, and a single hidden layer with

Table 5 CPI_j for sustainability

Performance dimension (criteria)	Dimension identifier 'i'	Weight for criteria 'W_i'	Response to the criteria by the respondent 'k'	Weighted score $W_i \times S_j^i$
Income/profit	1	0.045497	3	0.136491
Production	2	0.074222	4	0.296888
Turn over	3	0.066679	3	0.200037
Return on investment	4	0.044688	5	0.22344
Increase in literacy rate	5	0.035198	4	0.140792
Drop in accidental rate	6	0.011196	5	0.05598
Fall in crime rate	7	0.018704	4	0.074816
Decline in patient admissions in hospitals	8	0.038731	4	0.154924
Increase in per capita income	9	0.036647	3	0.109941
Improved transport and communication facilities	10	0.120284	5	0.60142
Regularity of the employee	11	0.097249	4	0.388996
High unity and morale of the employees	12	0.410907	4	1.643628
		1		4.027353
$CPI_j = 80.55$				

'n' number of neurons (varied from 1 to 20). On the whole, a neural network architecture that uses linguistic inputs and outputs with numeric weights was developed by Park (1993). Khan (2012) in his article on performance analysis, has employed a feed forward neural network model consisting of one input layer, varied hidden layers with one output layer. The NN architecture developed for mapping the practices with dimensional performances is shown in Fig. 3.

4.5.1.3 NN optimization The architecture is optimised using the model created in the tool box of MATLAB (version 10a) and the error function 'mean square error' (MSE), which is given in the Eq. 18.

$$\mathrm{MSE} = \frac{1}{\mathrm{J}} \sum_{\mathrm{i}=1}^{\mathrm{J}} \left[\frac{1}{12} \sum_{\mathrm{i}=1}^{12} (\mathrm{PWP}_{\mathrm{ij}}^{\mathrm{A}} - \mathrm{PWP}_{\mathrm{ij}}^{\mathrm{E}})^2 \right] \tag{18}$$

where, MSE—mean sum of the square 'i', $\mathrm{PWP}_{\mathrm{ij}}^{\mathrm{A}}$—actual percent weighted performances ($\forall \mathrm{i} = 1-12, \forall \mathrm{j} = 1-\mathrm{J}$), $\mathrm{PWP}_{\mathrm{ij}}^{\mathrm{E}}$—estimated percent weighted performances ($\forall \mathrm{i} = 1-12, \forall \mathrm{j} = 1-\mathrm{J}$), i—performance dimension identifier, j—industry identifier, J—no. of industry

Table 7 shows the performance (MSE) of the NN obtained on training with 100 data sets (taken from the Table 6) at various learning rates (0–1, 0.01 increments), number of neurons in the hidden layer, ranging between 1 and 20 and fixed epoch as 1000. The results revealed that the configuration, one that has minimum MSE, corresponds to the NN with eight neurons in the hidden layer at the learning rate of 0.8.

Table 6 Sample input and output data of 120 responses

Respondent identifier ‘j’	Input: sustainable practices ‘m_p’ Practices ‘p’ on its operational modes ‘m’											Output: target performance scores PWP_{ij}^{A} Economic, social and socio-economic				
	Practice 1					Practices 2–5	Practice 6									
	1	2	3	4	5	8…24	26	27	28	29	30	1	2	3…10	11	12
1	0	1	0	0	0	…	0	0	0	0	1	2.72976	4.45332	…	9.7249	5.848701
2	1	0	0	0	0	…	0	0	0	0	1	2.72976	4.45332	…	9.7249	5.848701
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
100	0	0	1	0	0	…	1	0	0	0	0	4.5496	7.4222	…	9.7249	5.848701
…	0	1	0	0	0	**…**	0	1	0	0	0	1.49632	7.77992	…	4.4688	9.7249
119	0	0	0	0	1	…	1	0	0	0	0	3.63968	9.7249	…	4.45332	5.848701
120	1	0	0	0	0	8…24	0	0	1	0	0	4.45332	4.4688	…	4.45332	5.848701

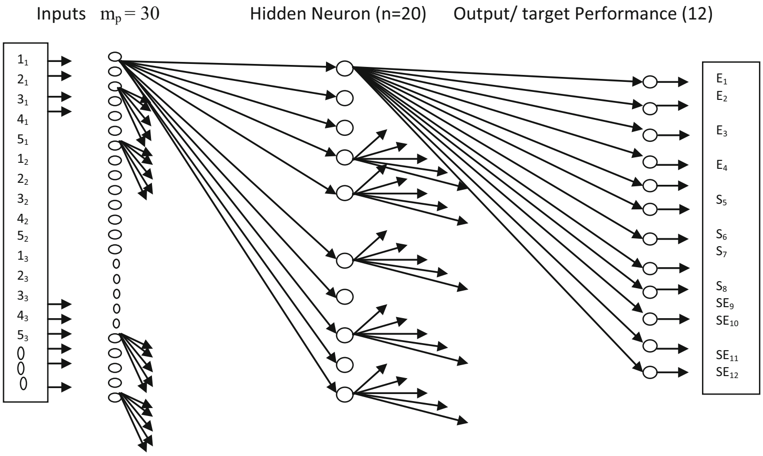

Fig. 3 NN architecture of practice intensity and dimensional performance model. Sustainable environmental practices (30) as inputs and 1–12 (*right*) performance dimensions as output to the network

4.5.1.4 Validation The learned NN configuration is tested for its validity with the remaining 20 data sets to confirm the prediction of the dimensional performance of the proposed NN model (101–120 in Table 6). Table 8 furnishes the absolute deviation (AD) between results obtained from MADM and NN output for all the performance dimensions of the test data. The mean absolute deviation ranges between 0.208922 and 4.4330936 and highlights it's much lesser deviation. This validates the learning of the NN configuration.

4.5.2 Performance estimation

The sustainability program is decoded to the performance modes m_p (for all p = 1−6), The value of X_{m_p} whose value is 1, indicates the selected sustainability program of mth mode at pth practice (i.e. m_p) In this illustrative example, $X_{m_p} = 1$ for the following binary variables: X_{5_1}, X_{4_2}, X_{1_3}, X_{5_4}, X_{2_5} and X_{3_6}. Hence the decoded value for input to NN are: $m_1 = 5$; $m_2 = 4$; $m_3 = 1$; $m_4 = 5$; $m_5 = 2$ and $m_6 = 3$.

The trained NN provides the $S^i_{m_p}$ values as the output. Then the $S^i_{m_p}$ values are converted to E, S and SE scores for the given sustainability program using the following equations.

$$E = \sum_{p=1}^{6} \sum_{m=1}^{5} \sum_{i=1}^{4} S^i_{m_p} \tag{19}$$

$$S = \sum_{p=1}^{6} \sum_{m=1}^{5} \sum_{i=5}^{8} S^i_{m_p} \tag{20}$$

$$SE = \sum_{p=1}^{6} \sum_{m=1}^{5} \sum_{i=9}^{12} S^i_{m_p} \tag{21}$$

The E, S and SE values obtained, as NN evaluation, from the above Eqs. 19–21 are E = 12.759, S = 7.1481 and SE = 38.4696.

Table 7 Minimum deviation arrived between the actual and NN results at varied learning rates and hidden neurons

LR	Hidden neuron																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	5.068	5.901	5.239	5.668	5.027	5.484	5.069	5.466	5.986	5.456	5.597	5.824	4.931	5.687	4.810	4.763	5.062	5.362	5.368	5.436
0.1	5.279	5.188	5.423	6.079	5.456	5.643	5.151	4.817	5.009	4.720	4.802	4.734	5.329	4.734	4.954	4.744	5.080	4.918	5.270	5.284
0.2	4.934	5.727	5.962	5.877	5.427	5.250	5.577	5.256	4.902	4.974	5.302	5.411	5.630	5.194	5.645	5.145	5.611	4.957	5.312	5.663
0.3	5.250	5.704	5.939	5.765	5.694	5.165	5.037	5.072	4.729	4.937	4.879	4.870	4.831	5.648	4.977	4.812	5.032	4.907	5.270	4.806
0.4	4.828	5.971	6.206	5.630	5.931	4.879	5.514	5.574	5.183	5.150	4.923	4.894	4.946	4.874	5.596	5.283	5.168	5.496	5.579	5.445
0.5	5.127	5.424	5.659	5.736	5.447	5.722	5.345	5.216	5.480	4.876	4.786	5.029	4.859	5.328	4.746	5.258	5.346	4.768	4.944	5.309
0.6	4.728	5.615	5.850	5.777	5.001	5.733	4.886	4.792	5.339	4.735	4.787	5.387	5.272	4.928	4.740	5.283	5.004	5.153	5.366	5.434
0.7	5.366	5.052	5.287	5.238	5.438	4.784	5.078	5.283	4.874	5.650	5.164	5.386	4.949	5.067	4.804	5.411	5.208	5.233	5.306	5.376
0.8	5.036	5.434	5.669	6.016	5.139	5.476	4.841	**4.633**	5.470	5.346	4.921	5.156	5.130	5.652	4.818	5.646	5.514	4.702	4.985	5.165
0.9	4.917	5.485	5.720	5.250	5.869	5.309	5.165	4.763	4.769	5.006	5.149	5.398	5.189	5.570	4.936	4.780	5.542	5.663	5.001	5.626
1.0	5.166	5.806	6.041	5.296	5.135	5.228	5.265	5.504	5.205	4.865	5.371	4.755	4.839	5.598	5.102	5.567	5.147	5.061	5.039	5.430

The number in bold indicates minimum deviation error

Table 8 Absolute deviation between MADM and NN output for 12 performance dimensions

S. no	Absolute deviation											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.987431	0.626345	0.779685	1.152416	0.084631	0.173898	0.473436	0.669830	0.527580	1.761546	1.145827	3.253519
2	0.077503	0.257072	0.972001	0.308582	0.004685	0.229648	0.134683	1.093052	1.063593	0.600128	0.258859	0.686814
3	0.515382	0.995205	2.608122	0.223603	0.578264	0.425177	0.684720	0.395435	0.799506	5.987626	6.789385	5.2548
4	0.987190	1.743324	1.708235	1.238816	0.812590	0.206794	0.149238	0.376524	0.494522	1.745826	2.716949	0.56039
5	0.046706	1.814015	1.724607	0.273625	0.653400	0.013214	0.630504	0.538649	0.368821	2.094910	1.571801	6.164319
6	1.192830	1.117036	0.510706	1.126718	1.009447	0.335103	0.305363	1.662876	0.795487	2.224619	0.491798	5.26967
7	0.086852	1.730553	2.202168	1.534071	1.637636	0.111563	0.642280	0.082058	0.243269	3.634618	6.922465	6.5487
8	1.159820	1.930710	1.887582	1.130655	0.973404	0.122506	0.073564	0.078842	0.751944	1.970940	0.287054	4.952272
9	0.083092	2.724971	2.310970	0.314799	0.014350	0.233045	0.610438	0.441425	0.408893	3.058093	0.371771	8.661219
10	0.891436	4.055162	0.893787	0.589918	0.779617	0.234936	0.247144	1.289344	0.485926	2.556101	0.074809	6.35874
11	0.041660	1.826072	3.064823	1.166837	0.748859	0.014690	0.491017	0.543882	0.362030	2.677723	1.541260	2.100504
12	0.862831	0.328665	1.724151	0.273804	0.653359	0.210861	0.117766	0.236586	0.363949	0.313914	0.368932	6.172546
13	0.862900	2.640056	0.942956	0.273690	0.050826	0.237032	0.630446	0.538274	1.102106	2.718872	4.260801	2.049858
14	0.142644	3.671391	0.694562	0.250016	0.550689	0.069570	0.284636	0.739879	0.611298	1.146127	7.397054	3.909654
15	0.962893	2.052182	0.811631	0.631495	0.644183	0.490386	0.477312	1.417494	0.496931	1.951272	0.984005	2.994211
16	0.035299	0.356826	0.405979	0.621520	0.742136	0.240517	0.115972	0.550712	0.353837	4.588272	1.500701	2.164348
17	0.862921	2.640005	0.942925	0.620063	0.653184	0.210804	0.491794	1.785579	0.363825	2.718726	4.260800	2.049739
18	0.052948	1.168933	1.725025	0.594796	0.691468	0.227560	0.245677	0.492762	1.048052	0.400154	1.957229	7.066225
19	1.149549	2.498063	0.567550	0.237901	0.257608	0.098443	0.449065	0.842985	0.737846	6.703695	2.171406	4.860988
20	0.193189	0.580024	0.722870	1.187930	1.760866	0.292683	0.102080	0.712956	0.071413	6.261342	0.776762	5.540201
% Mean absolute deviation	0.559754	1.73783	1.360017	0.687563	0.66506	0.208922	0.367857	0.724457	0.572541	2.755725	2.292483	4.330936

Table 9 Optimal solutions obtained with different maximum number of iterations

Maximum no. of iterations	100	500	1000	2000	5000	10000
Performance 'Z^{Opt}'	50.1672	50.5937	51.9148	52.2605	56.6913	56.6913
Computational time	434.5044	1841.611	3155.42	2980.012	5687.255	12222.63

4.6 Threshold checking module

The expected performances of the sustainability program, which are derived from the output of NN, are checked whether all of them meet the minimum threshold respectively E_{min}, S_{min} and SE_{min}. On satisfaction of the above module condition, the module proceeds to optimal solution update module. Otherwise, the module bypasses to termination checking module. Since, the economic ($E = 12.759$), social ($S = 7.1481$) and socio-economic ($SE = 38.4696$) values of the current solution meet their required respective threshold values, the algorithm proceeds to optimal solution update module.

4.7 Optimal solution update module

The overall performance Z, which is the sum of E, S and SE (i.e. $Z = E+S+SE$), is compared with Z_{opt}. If Z is found greater than Z_{Opt}, then Z is set as Z_{opt} and the current sustainability program X_{m_p} ($\forall p = 1-6$, $\forall m = 1-5$) is updated as $X_{m_p}^{Opt}$. In the first iteration, the value of Z (58.3767) is greater than the initial Z_{opt} value of 0. Hence, the current Z value of 58.3767 becomes the updated Z_{opt}.

4.8 Termination check module

The termination criterion often used in exploration search methods is either minimum error or maximum number of iterations. As these approaches are random walk search approaches, the errors between consecutive solutions (difference in objective values) may get frozen at early stage of exploration itself with inferior values and would lead to premature convergence. On the other hand, the criterion, maximum number of iterations, when set values are more than required, would lead to higher computation, but result a solution closer to optimal. As the objective of the model is to find optimal solution, ignoring time complexity, this paper uses maximum number of iteration as the termination criterion. In this model formulation, there are 15625 possible combinations of X_{m_p} sets (decision variables) and solutions available for evaluation. Table 9 shows the optimal solutions obtained for the sample problem under different It_{max} values. The results point out that the optimal solutions for 5000 and 10000 iterations are same and hence, it can be accepted that It_{max} can guarantee optimal or near optimal solution. On this concern, the maximum number of iteration is set as 10000. The algorithm terminate when it reaches it_{max} (i.e. $it \geq it_{max}$), on termination it proceeds to output module. Otherwise, it goes to *generation of sustainability program module*.

The iteration of the algorithm will consider the maximum count of iteration 'it_{max}' = 1000, where the initiation begins in iteration '1'.

Table 10 Effect of budget on sustainability performance

Problem parameter				Optimal results obtained by NN				
B_{max}	E_{min}	S_{min}	SE_{min}	X_{mp}^{Opt}	E^{Opt}	S^{Opt}	SE^{Opt}	Optimal performance 'Z'
20	15	7	10	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
25	15	7	10	1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0	22.9425	9.7519	11.2489	43.9432
30	15	7	10	0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0	23.1085	7.4897	15.5694	46.1677
35	15	7	10	0 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0	18.4517	8.5479	19.5889	46.5885
40	15	7	10	0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0	22.5548	10.182	23.3107	56.0474
45	15	7	10	0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0	15.4899	9.9827	30.6387	56.1113
50	15	7	10	0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1	18.4596	9.4571	31.2666	59.1833

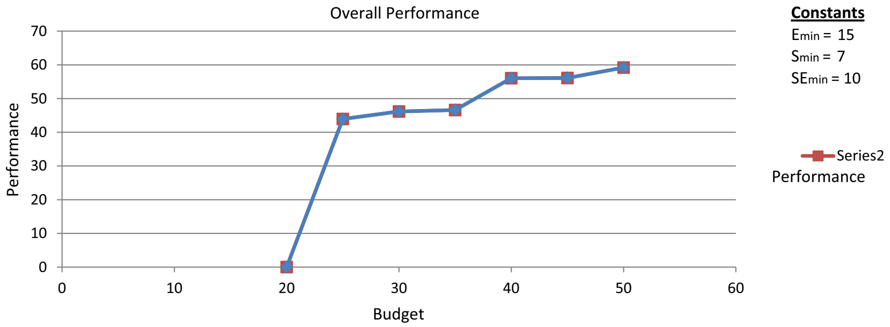

Fig. 4 Budgets versus performances

4.9 Output module

The output module will provide the optimal sustainability program '$X_{m_p}^{Opt}$' for maximum performance 'Z_{Opt}' that has evolved during the random search process. The optimal sustainability program is ['$X_{m_p}^{Opt}$' $= X_{5_1}, X_{3_2}, X_{5_3}, X_{3_4}, X_{5_5}$ and X_{2_6}] and its corresponding operational performance =[72.9634 %].

5 Sensitivity study

This section studies the variations in optimal sustainability program and their performance keeping the optimal cost matrix as shown in Table 3 under various environments, i.e. different values on B_{max}, E_{min}, S_{min} and SE_{min}. The effects of such parameters are detailed in the following Sects. 5.1–5.4.

5.1 Effect on budgetary limit

Budget is the limiting factor to implement the strategies. The firms would be interested to find the potential increase in their performances with the subsequent increase in the budget. On the above consideration, this section studies the effect of sustainable practices on sustainable performance under the conditions of varied budget limits (B_{max}: 20–50) keeping the threshold values (i.e. $E_{min} = 15$, $S_{min} = 7$ and $SE_{min} = 10$) and the cost matrix (i.e. Table 3) as constants. Table 10 shows the sustainable performances obtained for the various budget limits and the same is presented in Fig. 4. They indicate the followings:

- No feasible solution (i.e. solution that could not meet any one of the threshold values) is possible if the budget is less than INR 25,00,000 and it can be generalized that the target threshold values determine the minimum budget required;
- Marginal increase in sustainability performance is experienced with increase in the budget beyond INR 25,00,000 and felt gradual increase in performance as the budget increases. This indicates that minor variations occur over certain budget range and depends upon the performances of the sustainability program.
- Whatever be the sustainability program the maximum sustainable performance achieved is between 40 and 70 %. This falls in the range of performances obtained during the training.

Table 11 Effect of E_{min} on sustainable performance

Problem parameter				Optimal results obtained by NN				
B_{max}	E_{min}	S_{min}	SE_{min}	X_{mp}^{Opt}	E^{Opt}	S^{Opt}	SE^{Opt}	Optimal performance 'Z'
25	7	7	13	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0	15.0024	7.5246	20.8586	43.3856
	10	7	13	1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0	15.8654	6.9875	21.3546	44.2075
	12	7	13	1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0	15.5871	7.3637	22.1797	45.1305
	14	7	13	1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1	14.0885	6.0032	25.112	45.2037
	15	7	13	0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0	16.7552	8.365	20.4949	45.6151
	16	7	13	1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0	16.0905	9.7504	20.9309	46.7718
	18	7	13	1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 1 0 0 0 0	20.5105	9.9783	21.1779	51.6649
	20	7	13	0 0 1 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0	20.41	5.9844	21.0785	47.4711
30	7	7	13	0 0 1 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0	17.8266	7.4798	13.4908	38.7972
	10	7	13	0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0	15.8319	7.4457	20.3769	43.6546
	12	7	13	1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 1 0 0 0 0	15.8184	7.5391	19.4416	42.7991
	14	7	13	1 0 0 0 0 0 0 0 0 1 0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0	15.5871	7.3637	22.1797	45.1305
	15	7	13	0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1	16.0885	7.5074	29.312	52.9079
	16	7	13	1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0	20.9552	8.3071	25.4906	54.7529
	18	7	13	0 0 0 0 1 1 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0	22.7807	8.6241	16.5225	47.9274
	20	7	13	1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0	21.1516	8.1034	21.2474	50.5024
35	7	7	13	0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1	18.2695	8.4354	26.1404	52.8453
	10	7	13	0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0	22.1479	7.1721	24.938	54.2579
	12	7	13	0 1 0 0 0 0 1 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 0 0 0 1	22.9519	8.4078	25.4581	56.8178
	14	7	13	0 0 1 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0	16.4082	8.76	30.8993	56.0675
	15	7	13	0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0	23.0779	10.2235	20.9109	54.2123

Table 11 continued

Problem parameter				Optimal results obtained by NN				
$B_{\max}$	$E_{\min}$	$S_{\min}$	$SE_{\min}$	X_{mp}^{Opt}	$\mathrm{E}^{\mathrm{Opt}}$	$\mathrm{S}^{\mathrm{Opt}}$	$\mathrm{SE}^{\mathrm{Opt}}$	Optimal performance 'Z'
	16	7	13	0 0 0 0 1 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0	16.47	9.8097	31.2666	57.5463
	18	7	13	0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0	18.1819	7.1604	25.4858	50.8281
	20	7	13	0 1 0 0 0 1 0 0 0 0 0 0 0 1 0 0 1 0 0 0 1 0 0 0 0 0 0 0 1 0	22.6109	8.8627	17.9465	49.4202
40	7	7	13	1 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0	18.6397	7.1542	19.653	45.4469
	10	7	13	1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 0 0 0 1	18.886	9.2441	25.4163	53.5464
	12	7	13	1 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0	17.0647	10.1752	25.0771	52.317
	14	7	13	0 0 1 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0	21.066	7.6144	26.523	55.2035
	15	7	13	0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0	17.1383	9.0636	31.2628	57.4647
	16	7	13	0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0	16.5577	8.0148	18.813	43.3856
	18	7	13	0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0	19.3376	8.1783	15.8681	43.384
	20	7	13	0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0	22.1303	9.0408	25.4179	56.5889
45	7	7	13	0 0 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0	9.8292	7.3233	23.9026	41.0551
	10	7	13	0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0	23.1085	7.6863	24.0367	54.8315
	12	7	13	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0	20.8682	8.4918	28.3673	57.7272
	14	7	13	0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0	22.7522	8.9195	22.4775	54.1492
	15	7	13	0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0	16.6571	7.7387	27.0183	51.4141
	16	7	13	0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0	22.9537	10.3049	15.3875	48.6461
	18	7	13	0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0	19.108	9.7709	29.9883	58.8673
	20	7	13	0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0	22.7678	8.3497	23.8809	54.9984
50	7	7	13	0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0	22.1101	8.1384	19.186	49.4345
	10	7	13	0 0 1 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1	19.3255	10.936	23.2849	53.5464
	12	7	13	0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0	20.9299	9.804	21.5878	52.317

Table 11 continued

Problem parameter				Optimal results obtained by NN				
$B_{\max}$	$E_{\min}$	$S_{\min}$	$SE_{\min}$	$X_{m_p}^{Opt}$	$\mathrm{E}^{\mathrm{Opt}}$	$\mathrm{S}^{\mathrm{Opt}}$	$\mathrm{SE}^{\mathrm{Opt}}$	Optimal performance 'Z'
	14	7	13	0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 1 0 0	21.9062	10.4756	22.8219	55.2035
	15	7	13	1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0	20.9253	9.5901	24.3647	54.8793
	16	7	13	0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0	21.0942	7.3565	17.7823	57.8265
	18	7	13	0 0 1 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0	22.1274	9.4358	25.0257	56.5889
	20	7	13	0 0 0 0 1 0 1 0 0 0 0 0 0 0 1 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0	23.9801	12.9642	25.0933	62.0376

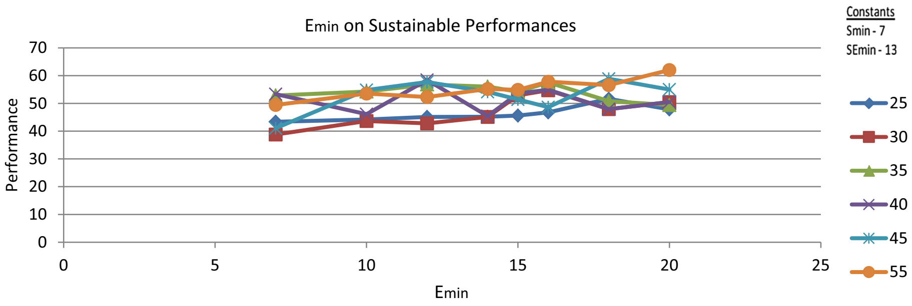

Fig. 5 E_{min} versus performances

5.2 Effect on threshold values E_{min}

The minimum target of the performance on economical dimensions to be met (E_{min}) differs with industry depending on the payback period. Smaller payback period projects warrants higher rate of returns (i.e. E_{min}). This section explores the effect of variation in E_{min} value on sustainable performance. The Table 11 provides the optimal performances obtained for various E_{min} (range 7–20 %) under different budgetary limits 'B_{max}' (range 25–50 lakhs), with constant threshold values S_{min} and SE_{min} of value 7 and 13 respectively, and the cost matrix (i.e. Table 3). Figure 5 presents the results graphically. The results presented in Fig. 5 convey that:

- Whatever be the budget allocation, E_{min} is obtained between the range of 35 and 65 % for any sustainable program.
- Sustainability performance lies in the specified range and there is no significant variation with limit in 'B_{max}' value. However, beyond certain limit, the increase in performance is marginal.
- As industries focus on the economical outputs, there is always possibility for attaining Emin as basic criterion.

5.3 Effect on threshold values S_{min}

The minimum performance on social dimensions (S_{min}) to be met varies with stringent nature of the product/process of an industry. More the stringency of the product/process of the industry deserves higher level of societal concern (i.e. S_{min}). This section explores the effect of variation in S_{min} value on sustainable performance. Table 12 provides the optimal performances obtained for various S_{min} (range 2–14 %) under different budgetary limits 'B_{max}' (range INR 25,00,000–50,00,000) with constant E_{min} and SE_{min} values of 15 and 13 respectively as shown in the cost matrix (i.e. Table 3). Figure 6 presents the results graphically. The results, presented in Fig. 6 convey that:

- Maximum performance achievable is at 8 % of S_{min} for any budget limit. Beyond this value, there is no feasible sustainable program and
- Varied performances (35–65 %) has been witnessed in the feasible region and hence it is data dependent.

Table 12 Effect of varied $S_{\min}$ on overall performance

Problem parameter				Optimal results obtained by NN				
$B_{\max}$	$E_{\min}$	$S_{\min}$	$SE_{\min}$	X_{mp}^{Opt}	E^{Opt}	S^{Opt}	SE^{Opt}	Optimal performance ‘Z’
25	15	2	13	1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0	18.8171	5.9114	15.4050	40.1335
	15	4	13	1 0 0 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 1 0	21.8540	4.4257	18.4948	44.7745
	15	6	13	0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0	23.0814	7.0019	27.9627	58.0461
	15	8	13	Infeasible				
	15	10	13	Infeasible				
	15	12	13	Infeasible				
	15	14	13	Infeasible				
30	15	2	13	0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0	17.9947	7.8600	16.7014	42.5560
	15	4	13	0 1 0 0 0 0 0 0 0 1 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0	16.0113	5.9007	27.6740	49.5860
	15	6	13	0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0 0 0	23.0764	9.1009	30.9762	63.1535
	15	8	13	1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0	23.0900	9.7414	30.9950	63.8263
	15	10	13	Infeasible				
	15	12	13	Infeasible				
	15	14	13	Infeasible				
35	15	2	13	0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0	22.7599	3.5704	16.7677	43.0980
	15	4	13	0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0	21.6288	5.3872	21.7565	48.7724
	15	6	13	0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 1	23.1049	7.8224	14.4929	45.4202
	15	8	13	0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0	15.5098	8.2731	31.1790	54.9619
	15	10	13	Infeasible				
	15	12	13	Infeasible				
	15	14	13	Infeasible				

Table 12 continued

Problem parameter				Optimal results obtained by NN				
$B_{\max}$	$E_{\min}$	$S_{\min}$	$SE_{\min}$	X_{mp}^{Opt}	$\mathrm{E}^{\mathrm{Opt}}$	$\mathrm{S}^{\mathrm{Opt}}$	$\mathrm{SE}^{\mathrm{Opt}}$	Optimal performance 'Z'
40	15	2	13	0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0	18.9108	7.0914	22.4920	48.4942
	15	4	13	0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 1	15.2751	8.3361	14.8200	38.4311
	15	6	13	0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0	18.6904	6.3633	24.5124	49.5660
	15	8	13	0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 1 0	15.3446	8.7745	22.0794	46.1986
	15	10	13	Infeasible				
	15	12	13	Infeasible				
	15	14	13	Infeasible				
45	15	2	13	0 0 0 1 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0	23.0987	3.1286	19.5549	45.7822
	15	4	13	0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0	16.8916	6.8378	20.9858	44.7152
	15	6	13	1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 0 0 1 0	21.3103	6.8516	15.5736	43.7354
	15	8	13	1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0	22.8125	10.3075	14.3680	47.4880
	15	10	13	Infeasible				
	15	12	13	Infeasible				
	15	14	13	Infeasible				
50	15	2	13	1 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 1	16.1910	4.2621	17.8103	38.2635
	15	4	13	0 0 0 1 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0	22.6997	6.5067	27.5331	56.7394
	15	6	13	0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0	18.6495	7.1544	14.6567	40.4606
	15	8	13	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 1	17.8211	10.2433	30.3488	58.4132
	15	10	13	Infeasible				
	15	12	13	Infeasible				
	15	14	13	Infeasible				

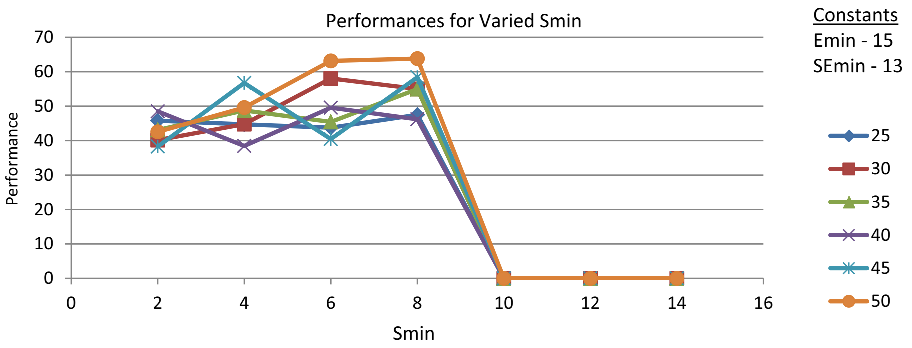

Fig. 6 S_{min} versus performances

5.4 Effect on threshold values 'SE_{min}'

The minimum performance on socio-economical dimensions (SE_{min}) to be achieved differs with industry depending on the country's living standards. Higher standard of living is associated with high level of SE_{min}. This section explores the effect of variation in SE_{min} on sustainability performance. Table 13 provides the optimal performances obtained for various SE_{min} (range 5–55 %) under different budgetary limits 'B_{max}' (range INR 25,00,000–50,00,000) with constants E_{min} and SE_{min} values 15 and 7 respectively and the cost matrix (i.e. Table 3). Figure 7 presents the results graphically. The results, presented in Fig. 7 convey that:

- A marginal variation in the sustainable performance (around 40–60 %) has been witnessed in the feasible regions.
- The achievable value of sustainable performance on SEmin is approximately 25 % for any amount of budget allocation. Beyond this value, there is no feasible sustainable program.

6 Conclusion

This paper, formulated a combinatorial optimization model to identify an optimal sustainability program for maximum sustainability performance of manufacturing firms under the limitation on budgetary and minimum threshold on economic, social and socio-economic criteria. A random search procedure (RSP) embedding the NN is developed to find the optimal sustainability program and the procedure is illustrated with a sample problem. A sensitivity analysis carried out to understand the behaviour of the model. The analysis reveals the following points:

- The effect of increase in budget limit (B_{max}) over certain level is very small.
- The minimum budgetary requirement is dependent on threshold values of E_{min}, S_{min} and SE_{min}.
- The economic threshold value E_{min} obtained in the range of 35 and 65 % for any sustainable program for and budget allocation.
- Maximum performance value achievable is at 8 % of Smin for any amount of budget allocation and varied performances of 35–65 % has been witnessed in the feasible region and hence it is data dependent.
- A marginal variation in the sustainability performance (around 40–60 %) has been witnessed in the feasible regions and sustainability performance on the socio-economic

Table 13 Effect of varied $\mathrm{SE}_{\min}$ on overall performance

Problem parameter				Optimal results obtained by NN				
$B_{\max}$	$E_{\min}$	$S_{\min}$	$SE_{\min}$	$X_{m_p}^{Opt}$	$\mathrm{E}^{\mathrm{Opt}}$	$\mathrm{S}^{\mathrm{Opt}}$	$\mathrm{SE}^{\mathrm{Opt}}$	Optimal performance 'Z'
25	15	7	5	0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0	22.8199	8.5438	6.8911	38.2549
	15	7	15	0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0	18.8341	9.7206	24.8967	53.4513
	15	7	25	0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0	19.0139	7.4221	26.8558	53.2918
	15	7	35	Infeasible				
	15	7	45	Infeasible				
	15	7	55	Infeasible				
30	15	7	5	0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0	19.9249	10.0754	14.1272	44.1275
	15	7	15	0 0 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0	16.8271	7.0936	25.3754	49.2961
	15	7	25	0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0	16.1145	7.3855	25.8105	49.3105
	15	7	35	Infeasible				
	15	7	45	Infeasible				
	15	7	55	Infeasible				
35	15	7	5	0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 1 0 0 0 0	16.4142	9.8792	17.1395	43.4330
	15	7	15	0 0 1 0 0 1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 0 1 0 0	18.9386	9.6027	24.4798	53.0211
	15	7	25	1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0	20.6650	9.0149	28.0832	57.7632
				Infeasible				
				Infeasible				
40	15	7	5	0 0 1 0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0	17.1074	9.4889	17.0594	43.6556
	15	7	15	0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 1 0 0	19.7553	8.7053	19.4923	47.9529
	15	7	25	0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0	23.0606	8.1816	30.7423	61.9845
				Infeasible				
				Infeasible				

Table 13 continued

Problem parameter				Optimal results obtained by NN				
$B_{\max}$	$E_{\min}$	$S_{\min}$	$SE_{\min}$	X_{mp}^{Opt}	E^{Opt}	S^{Opt}	SE^{Opt}	Optimal performance 'Z'
45	15	7	5	0 1 0 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0 0	22.0000	7.9470	16.7654	46.7124
	15	7	15	0 0 1 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0	16.2078	7.5382	23.3191	47.0650
	15	7	25	1 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0	22.7589	9.4056	26.7906	58.9551
				Infeasible				
				Infeasible				
				Infeasible				
50	15	7	5	0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0	16.4284	7.0211	22.9876	46.4371
	15	7	15	1 0 0 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0	22.4846	7.1379	22.5555	52.1780
				0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0	16.2989	7.3279	30.1613	53.7881
				Infeasible				
				Infeasible				
				Infeasible				

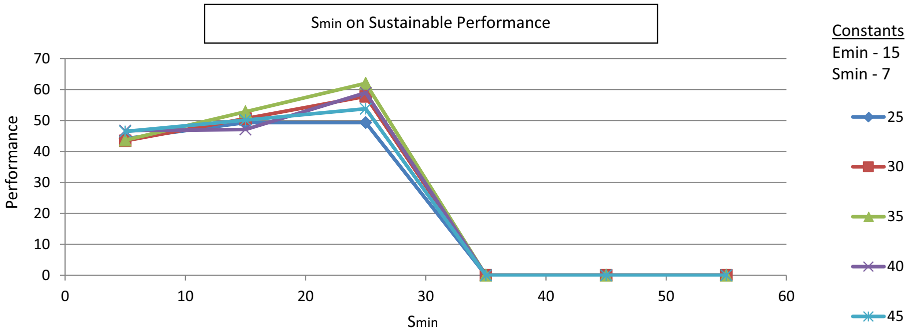

Fig. 7 SE_{min} versus performances

threshold value SEmin is feasible approximately around 25 % for any amount of budget allocation. Beyond this value, there is no feasible sustainable program.

The implications of sustainability program model proposed and analysed indicates that the industries can utilize the model to (1) devise a sustainable program suitable to their budget, (2) *derive maximum sustainability performance while satisfying the needs of their environment, operating policies, and government regulations* and (3) to determine possible range of performances (minimum to maximum) that is achievable in each dimension irrespective of the budget.

The developed model assumes that only one mode of operation for each sustainable practice. Besides, the number of modes of operations and number of practice have been limited between 5 and 6 respectively. The model can be expanded by including more number of practices, modes of operation and adoption of sustainability program. The data used for optimising NN (for evolving sustainable program) are obtained through survey instrument which is respondent perception and it is qualitative information. The weights are estimated using AHP approach. Though the discussions on the model analysis are based on the responses and the estimated weights, the outcome towards a sustainable program could be determined reasonably by this model. With higher samples, the model outcome could be generalised. The general limitations are sample size and the number of firms selected within manufacturing sector. The discussions and inferences are based on 120 samples. Strong voluntary participation of industry leaders in the future would uplift the sustainability studies.

Appendix: survey instrument

See Tables 14, 15, 16, 17, 18, 19.

Respondent's details

Name						
Age						
Name of the industry						
Current Designation						
Other Designations worked						
Experience in number of years	In present company					
	Total					
Educational Qualification (Sort from Highest to lowest)						

Table 14 General (A): company details

Q. no	Particulars	Options (by providing √ mark)				
A1	Location	Tropical	Hill station	Coastal	Plains	River Basin
A2	Zone	Rural Area	State Industries Promotion Corporation	Export Processing Zone	Special Economic Zone	Technology Park
A3	No. of employees	1–50	51–100	101–200	201–500	≥501
A4	Work force	Contract (C)	Temporary (T)	C + P	T + P	Permanent (P)
A5	Market area	State (S)	Regional (R)	National (N)	Inter National (I)	Both (N + I)
A6	Regulatory body	Industrial Association	Local	State	Central	International
A7	Certification	BIS	ISI	EU/UN	ISO	Non-standard

Table 15 (B) Categorization of product/process details

Q. no	Particulars	Your feed back (by providing $\surd$ mark)				
B1	Nature of waste	Non recyclable	Recyclable	Partial recyclable	Negligible waste	Zero waste
B2	Quantum of emission by the product expressed as % of fuel consumption	$\geq 50\,\%$	50–21 %	20–6 %	5–1 %	$\leq 1\,\%$
B3	Quantum of effluentresulted by the process expressed as % of processing material	$\geq 50\,\%$	50–21 %	20–6 %	5–1 %	$\leq 1\,\%$
B4	Environment regulations governing the process/product	Air pollution act	Soil pollution act	Water pollution act	Industrial waste act	Environmental protection act
B5	Pollution impact	Air	Soil	Water	Man kind	Ozone layer
B6	Water source	River/lake	Ground water	Rain water	Municipal water	Other

Table 16 (C) Environmental/sustainable practices

Q. no	Particulars	Your feed (by providing $\surd$ mark)				
C1	Training on sustainable practice to employees	Yearly	Half yearly	Quarterly	Bimonthly	Monthly
C2	Frequency of environmental practices audit	Yearly	Half yearly	Quarterly	Bimonthly	Monthly
C3	Environmental management system	Nil	Green manufacturing	Cleaner production	In campus ETP/STP plants	ISO 14000
C4	Proportion of employees involved in R&D activities	$\leq 1\,\%$	1–5 %	6–15 %	16–30 %	$\geq 30\,\%$
C5	Proportion of expenses from turn over for R&D activities	≤ 0	1–5 %	6–20 %	21–50 %	$\geq 50\,\%$
C6	Quality/management practices	Six sigma	Product chart	EOQ	Zero defect	Eco friendly

Table 17 (D) Economic performance

Q. no	Particulars	Your feed (by providing √ mark)				
D1	Income/profit	Poor	Below average	Average	Above average	Excellent
D2	Production	Poor	Below average	Average	Above average	Excellent
D3	Turn over	Poor	Below average	Average	Above average	Excellent
D4	Return on investment	Poor	Below average	Average	Above average	Excellent

Average during last 5 years: Poor = −30 %≤, Below average = −29 to − 6 %, Average = −5 to 5 %, Above average = 6−29 %, Excellent = ≥30 %

Table 18 (E) Societal performance

Q. no	Particulars	Your feed (by providing √ mark)				
E1	Increase in literacy rate	Very low	Low	Medium	High	Very high
E2	Drop in accidental rate	Very low	Low	Medium	High	Very high
E3	Fall in crime rate	Very low	Low	Medium	High	Very high
E4	Decline in patient admissions in hospitals	Very low	Low	Medium	High	Very high

Proportional change during last 5 years: Very low = −30 %≤, Low = −29 to − 6 %, Medium = −5 to 5 %, High = 6−29 %, Very high = ≥30 %

Table 19 (F) Socio-economic performance

Q. no	Particulars	Your feed (by providing √ mark)				
F1	Increase in per capita income	Very probably not	Probably not	Probably	Very probably	Definitely
F2	Improved transport and communication facilities	Very probably not	Probably not	Probably	Very probably	Definitely
F3	Regularity of the employee	Very probably not	Probably not	Probably	Very probably	Definitely
F4	High unity and Morale of the employees	Very probably not	Probably not	Probably	Very probably	Definitely

Proportion change during last 5 years: Very probably not = −30 %≤, −29 to − 6 % = Probably not, −5 to 5 % = Probably, 6−29 % = Very probably, ≥30 % = Definitely

References

Alshamrani, O. S., Galal, K., & Alkass, S. (2014). Integrated LCAeLEED sustainability assessment model for structure and envelope systems of school buildings. *Building and Environment*, *80*, 61–70.

Bouchery, Y., Ghaffari, A., Jemai, Z., & Dallery, Y. (2012). Including sustainability criteria into inventory models. *European Journal of Operational Research*, *222*, 229–240.

Chan, J. W. K., & Tong, T. K. L. (2007). Multi-criteria material selections and end-of-life product strategy: Grey relational analysis approach. *Materials and Design*, *28*, 1539–1546.

Chinchuluun, A., & Pardalos, P. M. (2007). A survey of recent developments in multi-objective optimization. *Annals of Operations Research*, *154*, 29–50.

Choi, T. (2014). Sustainable management of mining operations with accidents: A mean-variance optimization model. *Resources Policy*. doi:10.1016/j.resourpol.2014.02.003.

Curkovic, S. (2003). Environmentally responsible manufacturing: The development and validation of a measurement model. *European Journal of Operational Research*, *146*, 130–155.

Delmas, M. (2001). Stakeholders and competitive advantage: The case of ISO 14001. *Journal of Production and Operations Management*, *10*(3), 343–358.

Ding, Y., Feng, Q., Wang, T., & Fu, X. (2014). A modular neural network architecture with concept. *Neurocomputing*, *125*, 3–6.

Faulkner, W., & Badurdeen, F. (2014). Sustainable value stream mapping (Sus-VSM): Methodology to visualize and assess manufacturing sustainability performance. doi:10.1016/j.jclepro.2014.05.042.

Florez, L., & Castro-Lacouture, D. (2013). Optimization model for sustainable materials selection using objective and subjective factors. *Materials and Design*, *46*, 310–321.

Govindan, K., Jafarian, A., Khodaverdi, R., & Devika, K. (2014). Two-echelon multiple-vehicle location-routing problem with time windows for optimization of sustainable supply chain network of perishable food. *International Journal of Production Economics*, *152*, 9–28.

Jayal, A. D., Badurdeen, F., Dillon, O. W., & Jawahir, I. S. (2010). Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. *CIRP Journal of Manufacturing Science and Technology*, *2*, 144–152.

Kates, R. W., Clark, W. C., Corell, R., Hall, M. J., Jaeger, C. C., Lowe, I., et al. (2001). Sustainability science. *Science*, *292*, 641–642.

Khan, M. N. A. (2012). Performance analysis of Bayesian networks and neural networks in classification of file system activities. *Journal of Computers and Security*, *31*, 391–401.

Klassen, R. D., & McLaughlin, C. P. (1996). The impact of environmental management on firm performance. *Informs a Journal of The Institute for Operations Research and the Management Sciences*, *42*, 1199–1214.

Kuik, O. J., & Gilbert, A. J. (1999). Indicators of sustainable development. In J. C. J. M. Van den Bergh (Ed.), *Handbook of Environmental and Resource Economics* (pp. 722–730). Cheltenham: Edward Elgar.

Linke, B. S., Corman, G. J., Dornfeld, D. A., & Tönissen, S. (2013). Sustainability indicators for discrete manufacturing processes applied to grinding technology. *Journal of Manufacturing Systems*, *32*, 556–563.

López-Villarreal, F., Lira-BarragánL, F., Rico-Ramirez, V., María Ponce-Ortega, J., & El-Halwagi, M. M. (2014). An MFA optimization approach for pollution trading considering the sustainability of the surrounded watersheds. *Computers and Chemical Engineering*, *63*, 140–151.

Montabon, F., Sroufe, R., & Narasimhan, R. (2007). An examination of corporate reporting, environmental management practices and firm performance. *Journal of Operations Management*, *25*(5), 998–1014.

Nahorski, Z. & Ravn, H.F. (2000). A review of mathematical models in economic environmental problems. *Annals of Operations Research, 97*, 165–201.

Nidumolu, R., Prahalad, C. K., & Rangaswami, M. R. (2009). Why sustainability is now the key driver of innovation. *Harvard Business Review*, *87*, 57–64.

Pandian, G. S., Jawahar, N., & Nachiappan, S. P. (2013). Composite performance index for sustainability. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, *3*(1), 91–102.

Pandian, G. S., Jawahar, N., & Nachiappan, S. P. (2013). Questionnaire for the development of Environmental Regulation Management System for Indian Manufacturing Industries. *Management Arts-Elixir International Journal*, *56*, 13330–13343.

Park, J. J. (1993). *Neural Network Processing of Linguistic Symbols Using Multi-Level Grading Rule. Computer Science*. Tallahasse, FL, USA: Florida State University.

Rho, B. H., Park, K., & Yu, Y. (2001). An international comparison of the select of manufacturing strategy-implementation gap on business performance. *International journal of Production Economics*, *70*, 89–97.

Roberts, S. J. F., & Ball, P. D. (2014). Developing a library of sustainable manufacturing practices. *Procedia CIRP*, *15*, 159–164.

Rouhani, S., & Ravasan, A. Z. (2013). ERP success prediction: An artificial neural network approach. *Scientia Iranica, 20*(3), 992–1001.

Saaty, T.L. (1980). The analytic hierarchy process. New York: McGraw Hill. International, Translated to Russian, Portuguese, and Chinese, Revised editions, Paperback. (1996, 2000). Pittsburgh: RWS Publications.

Sarangi, P. P., Sahu, A., & Panda, M. (2013). A hybrid differential evolution and back-propagation algorithm for feedforward neural network training. *International Journal of Computer Applications*, *84*(14), 1–9.

Sezen, B., & Cankaya, S. Y. (2013). Effects of green manufacturing and eco-innovation on sustainability performance. *Procedia-Social and Behavioral Sciences*, *99*, 154–163.

Singh, L. P., Bhardwaj, A., & Sachdeva, A. (2006). Quality management practices vs. performance of SMEs: An empirical study of Indian industries. *Journal of Technology Management for the Global Future*, *5*, 2393–2399.

Subramanian, N., Abdulrahman, M. D., & Rahman, S. (2014). Sourcing complexity factors on contractual relationship: Chinese suppliers' perspective. *Production and Manufacturing Research: An Open Access Journal*, *2*(1), 558–585.

Triantaphyllou, E., & Mann, S. H. (1995). Using the hierarchy process for decision making in engineering applications: Some challenges. *Industrial Engineering Applications and Practice*, *2*(1), 35–44.

Yang, C. L., Lin, S., Chan, Y., & Sheu, C. (2010). Mediated effect of environmental management on manufacturing competitiveness: An empirical study. *International Journal of Production Economics*, *123*, 210–220.

Zhang, Q., Shah, N., Wassick, J., Helling, R., & Van Egerschot, P. (2014). Sustainable supply chain optimisation: An industrial case study. *Computers and Industrial Engineering*, *74*, 68–83.