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A Multi-Objective Particle Swarm Optimization Algorithm for Business Sustainability Analysis of Small and Medium sized Enterprises

--Manuscript Draft--

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Abstract:	Sustainability is the major issue of small and medium sized enterprises (SMEs) all across the globe. Although SMEs contribute to GDP of any country their negative contribution to environment is also significant. Prior studies on SMEs' sustainability mainly classified into three categories - the correlation between environmental and social practices with economic performance, sustainable supply chain performance measurement, and empirical research on sustainability practices. There is no study that objectively derives the sustainable structure of SMEs through optimal combination of sustainability practices (inputs) and performance (outputs). Therefore, the main objective of this paper is to generate optimal structure of sustainable SMEs by combining neural network and particle swarm algorithm while considering Multi-Objective framework. The study uses data from 54 SMEs of Normandy in France and 30 SMEs of Midlands in the UK. The data was gathered through questionnaire survey. As we do not have the explicit expression of our objective functions, we train a Neural Network (NN) on our databases in order to enable the generation of value of the different objectives for any profile. We design and run a multi-objective version of Particle Swarm Optimization (MPSO) to generate efficient companies' structures. The weighted sum method is then used for different weights. The comparison of observed data and the results of the PSO analysis facilitates to derive improvement measures for each individual SME.

Answers to reviewers comments.

Dear –Guest- Editor

We would like to thank you and thank the reviewers for their effort in commenting our paper. We have tried, in the revised version, to answer to all their concerns. We hope that the paper will fulfill your requirements.

All the best

The Authors

n.b. we have answered in Blue Below

COMMENTS FOR THE AUTHOR:

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Reviewer #1: Minor Revision

Few concerns about the paper:
I would like the authors to stress on the limitations of their approach and to propose ways to overcome these limitations. They can also provide the perspectives and potential applications. This may present this in a section preceding the conclusion.

Please look at the new section preceding the conclusion. We have also modified the conclusion consequently.

There are few repetitions in the text that should avoided. Look at the introduction for example. Some formatting of the figures and tables is required.

We have double checked the paper and eliminated the repetitions from the text and arranged the formatting.

Reviewer #2: The manuscript is clearly presented, well structured, well written, and easy to understand.

I would recommend to the authors to present ways to generalize such approach to qualitative researches and to stress on the limitations of such approach vis a vis other methodologies such as regression analysis for example.

Please look at the new section preceding the conclusion. We have addressed in the new section the reviewer's concern about limitations and generalizations. We have also addressed this in the new conclusion.

Reviewer #3: Definitely, the manuscript can be accepted for publication after providing a language revision and improving the discussion and conclusion (Section 6).

We have double checked the language of the paper and rearranged the conclusion.

A Multi-Objective Particle Swarm Optimization Algorithm for Business Sustainability Analysis of Small and Medium sized Enterprises

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ABSTRACT

Sustainability is the major issue of small and medium sized enterprises (SMEs) all across the globe. Although SMEs contribute to GDP of any country their negative contribution to environment is also significant. Prior studies on SMEs' sustainability mainly classified into three categories – the correlation between environmental and social practices with economic performance, sustainable supply chain performance measurement, and empirical research on sustainability practices. There is no study that objectively derives the sustainable structure of SMEs through optimal combination of sustainability practices (inputs) and performance (outputs). Therefore, the main objective of this paper is to generate optimal structure of sustainable SMEs by combining neural network and particle swarm algorithm while considering Multi-Objective framework. The study uses data from 54 SMEs of Normandy in France and 30 SMEs of Midlands in the UK. The data was gathered through questionnaire survey. As we do not have the explicit expression of our objective functions, we train a Neural Network (NN) on our databases in order to enable the generation of value of the different objectives for any profile. We design and run a multi-objective version of Particle Swarm Optimization (MPSO) to generate efficient companies' structures. The weighted sum method is then used for different weights. The comparison of observed data and the results of the PSO analysis facilitates to derive improvement measures for each individual SME.

Keywords: *Neural Network, Particle Swarm Optimization, Multi-objective Programming, Sustainability practices and performance*

1. Introduction

The literature of business disciplines increasing refers the term sustainability as an integration of social, environmental, and economic responsibilities (Seuring et al., 2008). About 68 percent of the Global 250 firms generated a separate annual sustainability report in 2004 which considered environmental, social, and economic issues, in contrast to the primary emphasis on environmental reporting in 1999; in addition, 80 percent of these reports discuss supply chain-related issues (KPMG, 2005). Although sustainability of large organizations as focal company has been considered extensively in prior research along with their supply chain, researches on small and medium sized enterprises' (SMEs) sustainability issues and challenges are relatively less.

SMEs are the main part of any economy. 90% of world businesses happen through SMEs, 50 – 60% of world population work in SMEs. However, economic sustainability of SMEs are uncertain due to intense competitions along with several other issues. SMEs are socially and environmentally vulnerable as quite often they require to priorities economic sustainability over environmental and social. Prior research on SMEs' sustainability emphasizes on the role of corporate social responsibility and environmental management system on SMEs' business performance. Kerr (2006) explores SMEs strategies and policies to manage environmental issues and pressures. Walker and Preuss (2008) demonstrate how public sector could promote sustainability through sourcing from SMEs. Jenkins (2009) presents a corporate social opportunity model, which is innovation led, for new market, and with a business model. Another paper (Moore and Manring, 2009) discusses several different incentives (e.g. attractive to local and global clients, developing network of sustainable SMEs) to optimize sustainability. More recently, Hoof and Theill (2014) reveal that collaboration capacity is essential for effective implementation of cleaner production, which provide competitive advantages for sustainable supply chain management. In his paper, Johnson (2015) analyses why particular SMEs are more likely to adopt sustainability management tools. Bourlakis et al. (2014) study the relationship between firm size and sustainability performance and reveal that small firms are top performers and excel in most sustainable performance measures. Huang et al. (2015) empirically investigate the pressures and drivers that have been experienced by Chinese manufacturing small and medium enterprises (SMEs) in terms of green supply chain management (GSCM). Jayaram et al. (2014) study supply chain capability of family owned SMEs in India. The work by Govindan et al. (2014) focuses on identifying barriers to the implementation of a green supply chain management based on procurement effectiveness. Energy efficiency has been recognized as a primary means to increase the competitiveness SMEs (Trianni et al., 2016). In summary, prior researches have revealed correlations of social and environmental sustainability with economic performance and explored means for achieving sustainability of SMEs. Although they are important to transform SMEs for higher sustainability, the research on effect of combined operational, environmental and social practices of SMEs on economic and overall sustainability performance is scant.

The main objective of this paper is to derive optimal structure of sustainable SMEs with the consideration of input variables (operational, environmental, social, and economic practices) and output variables (business growth, turnover and environmental performance). We study the effect of main business variables including environmental and social management on business growth, turnover and environmental performance. We consider a multi-objective optimization model for our study and optimize the following objectives: the turnover, the environmental management and the business growth. The management decision variables are practices related to demand management, supply chain management, internal process management, environmental and social management.

The remainder of the paper is organized in the following five sections. Section 2 introduces theoretical foundation of the paper covering multi-objective Pareto solutions, neural network, and Particle Swarm Optimization (PSO). Section 3 describes the methodology for undertaking this research. Section 4, presents the algorithm that has been used for analyzing the data. Section 5, demonstrates the results of the application of the proposed heuristic. Section 6 thoroughly discusses the results through explaining how these could facilitate both policy makers and individual SME owners to enhance sustainability performance.

2. Theoretical concepts

This section contains three parts. In the first part, we define the multi-objective programming formulation. We present the Pareto solutions and ways to generate them. In the second part, we provide the NN structure. In the last part, we explain our PSO heuristic.

2.1 Multi-Objective Pareto Solutions

Multi-objective Programming (MOP) has been intensively studied for more than four decades. It is used to deal with problems in which different objective functions are optimized simultaneously. In general, the MOP formulation is proposed in the following form:

$$\begin{aligned} &Max\ \ F(x)=\left\{ f_1(x), f_2(x),..., f_k(x)\right\} \\ &s.t. \quad x \in S \end{aligned} \qquad (1)$$

where the index k ($k \geq 2$) indicates the number of objective functions to optimize $f_i : \Re^n \rightarrow \Re$, $F(x)$ is the objective vector, the decision variable vector is $x=(x_1, x_2,..., x_n)$ and S represents the set of the feasible solutions.

Dominance is defined as follows: A decision vector $x' \in S$ is dominated by another $x \in S$ if $f_i(x) \geq f_i(x')$ for all $i=1,...,k$ and $f_j(x) > f_j(x')$ for at least one index j.

A decision vector $x' \in S$ is called Pareto optimal (or efficient) if there does not exist another $x \in S$ such that $f_i(x) \geq f_i(x')$ for all $i=1,...,k$ and $f_j(x) > f_j(x')$ for at least one index j.

The solution for the MOP is the set of all non-dominated solutions called the Pareto (or efficient) set.

There are several approaches to solve a MOP such as the ε-constraint approach, the goal programming (GP) approach and the weighted sum approach.

The ε-constraint method (Haimes et al., 1971) consists in minimizing a primary objective function and transforming the remaining objective functions into inequality constraints as follows:

$$\begin{aligned} & Max\ \ f_{\ell}\left(x\right) \\ & s.t\quad f_j\left(x\right) \geq \varepsilon_j\ \ for\ all\ \ j = 1,...,k, j \neq \ell \\ & \qquad x \in S \end{aligned} \tag{2}$$

where ε_j is the maximum of $f_j(x)$, $j \neq \ell$, $\ell \in \{1,..,k\}$.

We can prove that any unique solution for an ε-constraint problem is an efficient solution.

The GP is proposed by Charnes et al. (1955). In the GP approach, the DM defines the goal of each objective. In general, the goal $\overline{z}_i, \left(i = 1,...,k\right)$ is greater than maximum of $f_i\left(x\right), \left(i = 1,...,k\right)$. The aim is to minimize the deviations from goals. Therefore, the general GP model is as follows (Charnes and Cooper, 1963):

$$\begin{aligned} & Min\ \sum_{\mathrm{i=1}}^{\mathrm{k}} \delta_i^- + \delta_i^+ \\ & s.t\ \ f_i\left(x\right) - \delta_i^- + \delta_i^+ = \overline{z}_i\ \ for\ all\ \ i = 1,...,k \\ & \quad \delta_i^-, \delta_i^+ \geq 0\ for\ all\ \ i = 1,...,k \\ & \quad x \in S \end{aligned} \tag{3}$$

where δ_i^-, δ_i^+ are the negative and positive deviation variables from the ith goal. The obtained solution, if unique, is a Pareto optimal.

The weighted sum method was introduced by Gass and Saaty (1955), to transform a MOP problem into a uni-objective problem. Thus, a positive weight is assigned to each objective. Therefore, the objective is to maximize the weighted sum of all the MOP objective functions. The general weighted problem can be formulated as follows:

$$\begin{aligned} & Max\ \sum_{\mathrm{i=1}}^{\mathrm{k}} \lambda_{\mathrm{i}} f_i\left(x\right) \\ & s.t\quad x \in S \end{aligned} \tag{4}$$

where $\lambda_i > 0$ for all $i = 1,...,k$ are the weight coefficient of objective function f_i, with $\sum_{i=1}^{k} \lambda_i = 1$. An optimal solution of weighted sum method is also a Pareto optimal solution.

In our study, and to determine a sample of efficient solutions, we use problem 4 for different weights and we consider our trained NN to generate the values of the two objective functions to be used by the MPSO algorithm.

Neural networks (NN)

The multilayer perceptron (MLP) method is the most studied NN. It has a feed forward structure due to the relation between inputs and outputs. Furthermore, the MLP technique starts by organizing the neurons, and then each layer considers the outputs of the previous layer as inputs. In general, the units are ordered in three types of layers, which are, input layers, hidden layers and output layers. (See Figure 1)

Figure 1. A two-layer artificial neural network with three inputs and two hidden units (Looney, 1997)

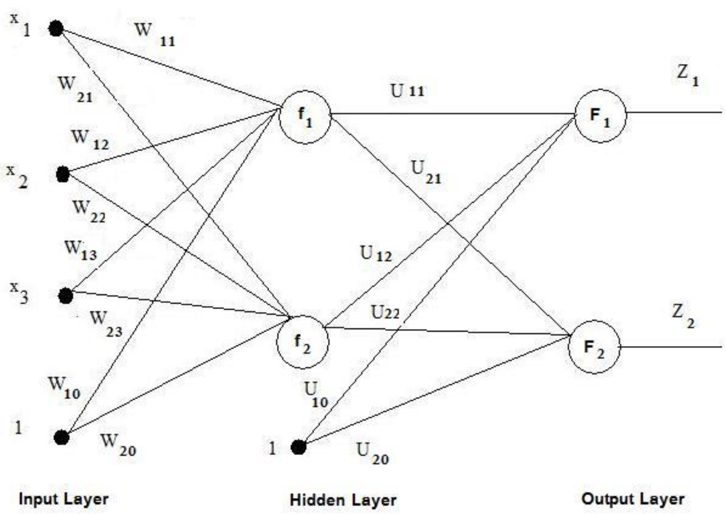


Figure 1 illustrates an example of MLP with three layers where W_{ij} are the weights and U_{ji} are the biases. The bias can be interpreted as a weight acting on an input clamped to 1 (Norgaard et al., 2000). F_j are objective functions used respectively to calculate intermediary outputs and activated outputs Z_j. The MLP aims to find the best weights that join the inputs to outputs by using an activation function. Different activation functions are proposed in the literature such as sigmoid, hyperbolic tangent and threshold (Hu and Hwang, 2001). The most used activation function in the MLP is the sigmoid defined as follows:

$$f(x) = \frac{1}{1+e^{-x/T}} \qquad (5)$$

where T is a temperature parameter. The formulation defining the output in the function of the inputs is as follows:

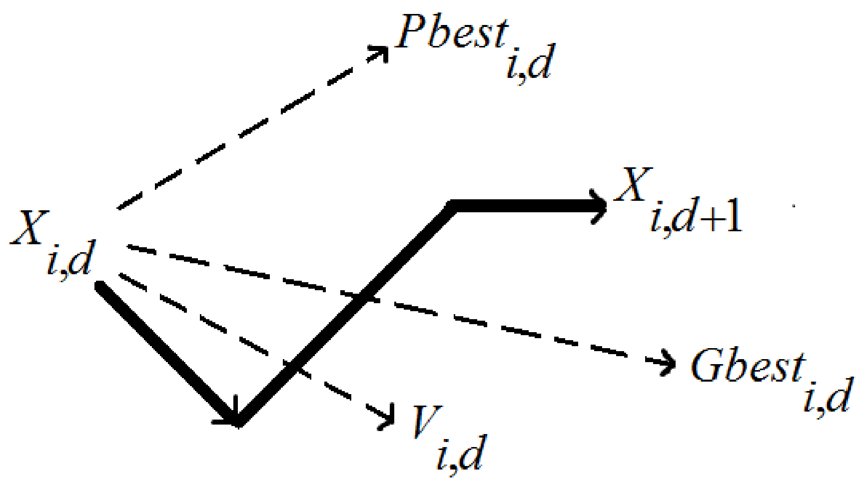
$$Z_j = g_j\left[x,\alpha\right] = F_j\left[\sum_{i=1}^{M} U_{ji} f_i\left(\sum_{l=1}^{N} W_{il} x_l + W_{i0}\right) + U_{j0}\right] \qquad (6)$$

where α is the parameter vector containing the adjustable parameters of the network. To train the MLP, we need to adjust weights by employing the Back propagation technique (Looney, 1997). This technique contains three steps. The first step initializes the weight set with random variables. The second step updates the weight set with a strategy helping to have a less sum-squared error between generated and observed results. In the third step, if a stopping criteria is met, the process is stopped else new weights are generated with the second step.

2.2 Particle Swarm Optimization (PSO)

Eberhart and Kennedy (1995) introduce the PSO method. This heuristic simulates the flying of particles in a multiple dimensional search space (Ben abdelaziz and El-baz, 2010). Each particle possess four parameters: velocity (V_i), position (X_i), position of the best fitness encountered by the particle ($pbest_i$) and best position of all particles ($gbest$). (See Figure 2)

Figure 2. Particle Swarm Optimization



The mathematical formulation to update the velocity is as follows:

$$V_i(d+1) = \omega V_i(d+1) + c_1 r_1\left(X_{pbest_i}(d) - X_i(d)\right) + c_2 r_2\left(X_{gbest}(d) - X_i(d)\right) \qquad (7)$$

where ω presents the inertia weights, c_1 and c_2 are random variables representing cognitive and social scaling parameters. r_1 and r_2 are random variables uniformly distributed in $[0,1]$. d is the dimensional variable. Therefore, the new particle position is calculated as follows:

$$X_i(d+1) = X_i(d) + V_i(d+1) \quad (8)$$

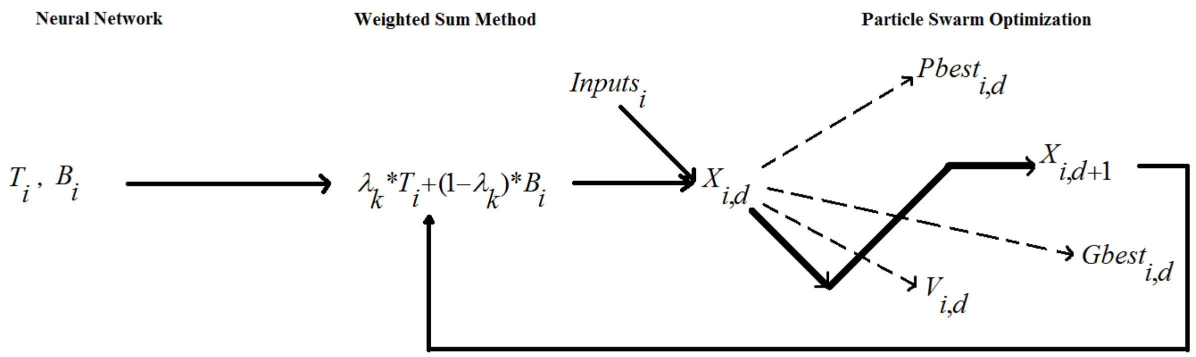
3. Methodology

The study uses both primary and secondary research methods. First, a thorough literature review is undertaken in order to develop a conceptual framework of SMEs sustainability structure. This study considers demand management, supply management, internal process management, environmental and social management as input variables, and turnover, business growth and environmental performance as output variables. Second, a questionnaire has been formed to gather the perceptions of SMEs managers and owners on sustainability practices and performances through survey method. The questionnaire is enclosed in Appendix A. Third, an algorithm has been developed using combined NN and MPSO method to formulate the optimal structure of sustainable SMEs. Forth, data has been gathered from 53 French SMEs from Normandy area, and 30 SMEs from Midlands in the UK using the questionnaire survey. The proposed algorithm is applied to the above two regions using the data gathered in the surveys in order to develop sustainable SMEs' structure.

4. The Proposed Algorithm

The proposed algorithm contains three steps. In the first step, we train our data to generate the best NN for the turnover, the environmental management and the business growth. In the second step, we adopt weighted sum method to transform a multi-objective problem into uni-objective problem. Therefore, we apply the values of the different weights to the objectives generated by the NN algorithm. Once the problem is transformed into a uni-objective problem, we use the PSO to find the best suitable combination of inputs that generates the highest weighted sum of turnover, environmental management and business growth. We note that the set of weights is defined as $(\lambda_k; k = 1, \dots, M)$. (See Figure 3)

Figure 3. Proposed solution



Part 1: Neural Network

- Run the NN algorithm to calculate activation outputs

  Neural Network algorithm:

  Step 1: Initialize inputs and outputs desired for the three objectives (These values are provided from the responses on the questionnaire)

  Step 2: For 1 to the number of inputs (N)

  - Calculate intermediary outputs
  - Adjust weights by using the back propagation method
  - Calculate activation outputs

  Step 3: Go to step 2 until stopping criteria are satisfied.

Part 2: Weighted sum method & PSO

For $k=1$ to the number of weights (M)

- Apply the weighted sum method.
- Run the PSO algorithm to find best structure for different weights.

  PSO algorithm:

  Step 1: Initialize all particle positions and velocities

  Step 2: For each particle:

  - Evaluate analysis function with used weights determined by NN algorithm in step 2
  - Evaluate values of its previous best position and global best position
  - Update particle velocities and positions

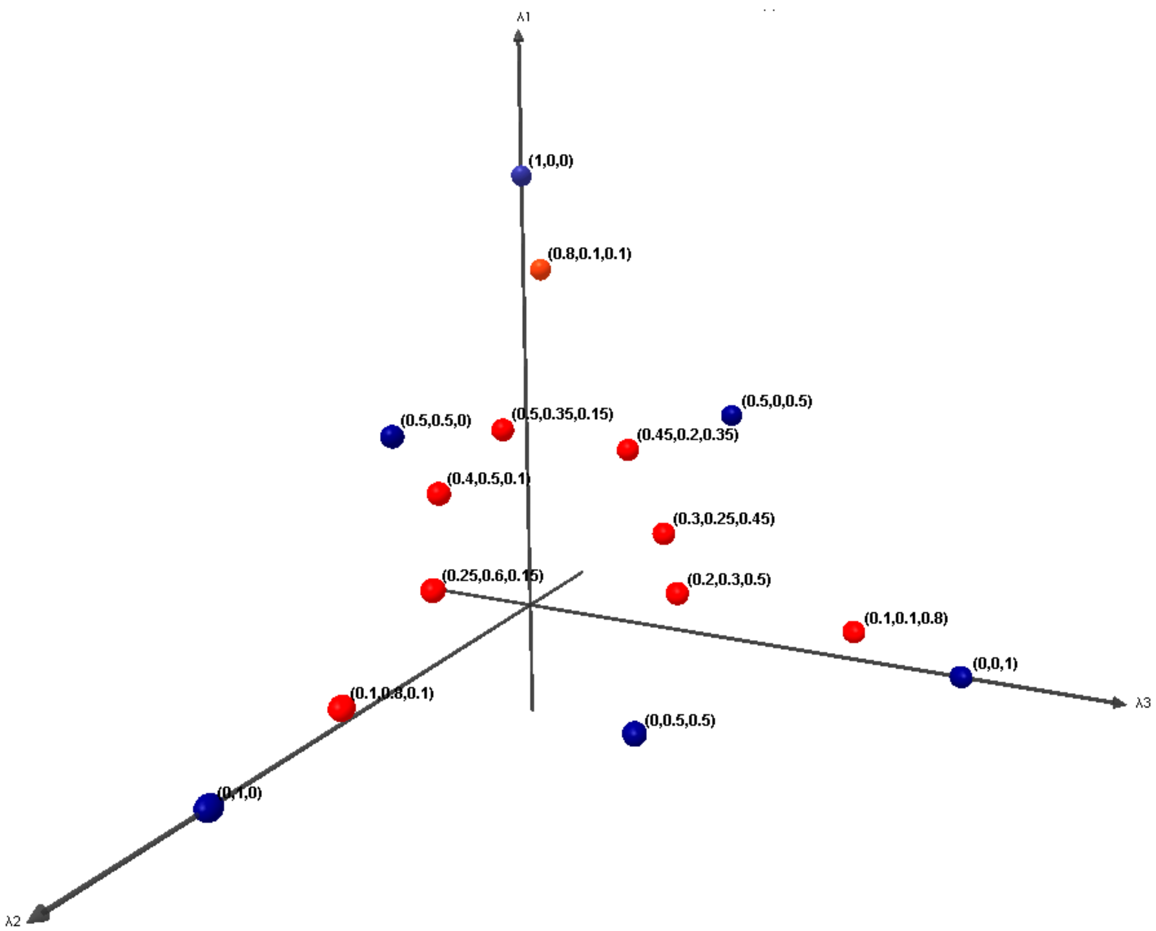
  Step 3: Go to step 3 until stopping criteria are satisfied.

5. Results and Implications

The above algorithm has been applied in two regions – Normandy in France and Midlands in the UK through collection of data from random SMEs using the questionnaire (appendix A) survey. Table 1 and 2 present the survey responses on observed inputs and outputs from the two regions along with the results of turnover, business growth and environmental performance of the SMEs derived through NN algorithm. The observed inputs: environmental practices, demand management, supply management, internal process management and social management are provided in columns 5, 6, 7, 8 and 9 respectively. The observed outputs – turnover, business growth and environmental performance are in columns 2, 3, and 4 respectively. The last columns 10, 11 and 12 are the results obtained after training the NN for the French and the UK databases. For example in table 1, the observed turnover, business growth and the environmental management for the DMU1 are equal to 4.5, 4 and 3.667. The generated values by the NN for the same variables are 4.549, 4.087 and 3.831. Table 3 presents the results of the NN when we consider both databases (French and the UK). The validation of the results of NN analysis is carried out through deriving Mean Absolute Percentage Error (MAPE) for each output variable for French, UK and combined data. All the MAPEs are within the desired limits.

As described in the previous section, table 4 provides optimal solutions for weighted sum problems considering different lambda values (See Figure 4). These solutions are Pareto efficient configurations regarding three outputs (i.e. turnover, business growth and environmental performance). Row 1 of table 4, for example, shows that the French SMEs' configuration with respect to environmental, demand, supply, internal process and social management are 3.54, 1, 2.59, 1 and 4 respectively along with outputs – turnover, business growth and environmental performance as 2.711, 1.697, and 3.497 respectively is a Pareto efficient for considering importance of turnover, business growth and environmental performance as 20%, 30% and 50% respectively. The corresponding optimal solution is 2.7998. The other rows of table 4 depict different possible combinations of importance of output variables. For French SMEs table 4 depicts various observations. French SMEs can achieve best sustainability solution with 10% importance in turnover, 10% in business growth and 80% in environmental performance. They are likely to achieve overall lower sustainability performance if they emphasize on turnover compared to other two output criteria. However, emphasize on business growth is likely to achieve moderate overall sustainability for French SMEs. Table 5 depicts results for the UK SMEs. This shows with 80% importance in business growth is likely to produce the best sustainability whereas 80% importance to environmental performance might produce the worst sustainability result, which is a contrast from the French SMEs outcomes. The table 6 combines French and UK companies' data, which depicts that the combined emphasize on turnover and business growth are likely produce the best sustainability result but only emphasize on business growth might produce worst result.

Figure 4. Lambda values



As per the PSO analysis (table 4) the optimal structure (with importance of 20% on Turnover, 30% on business growth and 50% on environmental performance) of SMEs in Normandy, France with respect to environmental practices, demand management, supply management, internal process management and social management is 3.54, 1, 2.59, 1, and 4 respectively. This would likely to result optimal turnover, business growth and environmental performance as 2.711, 1.697, and 3.497 respectively. If we compare these results with the observed data of specific SME as gathered through survey interviews, we can derive the improvement measures. As for example, SME1 in France has the following observed data (second row of table 7a) and optimal SME structure in the region (third row of table 7a). The forth row briefly explains the improvement measures. If the same SME intends to achieve best optimum sustainability results they have to emphasize on environmental performance (80%), over turnover (10%) and business growth (10%). The improvement measures in this circumstance will be altered as shown in table 7b. Similarly, table 8a and 8b show the improvement measures for SME1 of the UK for achieving optimal sustainability performance for 20% importance in turnover, 30% importance in business growth and 50% importance in environmental performance, and for 10% importance in turnover, 80% importance in business growth and 10% importance in environmental performance (best optimal) solution respectively. If this SME intends to make amendments in percentage of business objectives (in line with business environment) they are expected to undertake different improvement measures. The improvement measures could be derived considering the results from table 4 for the French SMEs, and table 5 for the UK SMEs with the consideration of various combinations of importance of output criteria in line with business environment.

6. Advantages and Limitations of the proposed combined neural network (NN) and particle swam optimization (PSO)

The objective of this study is to reveal the optimal structure of SMEs to achieve sustainability through most appropriate balance among economic, environmental and social performance. The study considers environmental practices, demand management, supply management, internal process management, and social management as input and turnover, business growth and environmental performance as output criteria for developing and testing most appropriate sustainability structure of SMEs. These criteria might vary across industries, geographical locations and over the period. In this study, we have adopted primary research approach, where we have gathered information on the criteria through questionnaire survey from the concerned stakeholders. Input criteria are subjective and we have adopted qualitative survey method using 1 – 5 Likert scale. Although the output criteria are objective we decided to gather information in 1 – 5 Likert scale through perception survey of the managers of the SMEs in order to keep parity of data collection between input and output criteria. The entire research could be undertaken using secondary information through an agreed scale of measurement. This limitation could easily be overcome by emphasizing gathering as much information as possible through secondary sources (e.g. published data) and adopting primary research method for the criteria for which it is impossible to get secondary data sources.

We have considered the combined NN and PSO approach to derive optimal structure of SMEs for achieving sustainability as this has advantages over other methods as stated earlier. However, there are other possible approaches that could have been undertaken instead, which would have resulted almost similar outcomes with a few constraints. The following paragraph briefly discusses a few alternative methods that could have been used instead of NN and PSO approach along with their pros and cons.

Multiple criteria decision making (MCDM) approaches (e.g. the analytic hierarchy process, the analytic network process, fuzzy theory etc.) help rank alternatives using multiple criteria (both objective and subjective) in multiple hierarchy (e.g. criteria, sub-criteria, and proxies), and in conflicting scenarios (i.e. each criterion can favour different alternative). This approach is suitable for benchmarking small number of SMEs on their sustainability performance but unsuitable for developing most optimal sustainability configuration of group of SMEs. Goal programming is another MCDM method that can formulate optimal structure of SMEs through setting up of a few goals / targets but this needs also objective information to model objective function and constraints to derive the variables (inputs and outputs). Data Envelopment Analysis (DEA) can also be used to model sustainability performance of SMEs, which enables segregate efficient and inefficient SMEs, and suggests improvement measures for the inefficient SMEs through benchmarking with the most appropriate one. The efficient SMEs could be considered as having optimal structure but they are mostly locally optimized than globally. Structural equation modelling (SEM) is another approach that helps SMEs to achieve sustainability. It helps develop relationship among the criteria and sub-criteria through regression modelling. Although it facilitates to improve sustainability performance by identifying the root causes of superior sustainability performance but fails to depict an optimal SMEs' structure.

The proposed combined NN and PSO approach that facilitates to develop optimal structure for sustainable SMEs has a few more limitations. Optimal structure of SMEs depends on the sample size, importance of the output criteria and accuracy of data gathered from the sample SMEs. This limitations could be overcome by selecting most appropriate sample, scientifically deriving the importance of the criteria and selecting the interviewees carefully to reduce biasness. Additionally, deriving the means for improvement for each participating SME could be challenging. However, engaging with the concerned SME's representatives and jointly deriving solutions could be the way forward.

As the criteria for sustainability practices and performances are subjective the most appropriate method would be one that can handle subjectivity and convert them into objective information. The combined NN and PSO approach can fulfil this requirement by converting survey responses in 1 – 5 scale to objective numbers. Additionally, it enables reveal optimal structure of SMEs through determining importance of the output criteria and vis a vis deriving desired inputs and outputs.

Similar approach could be adopted in other qualitative research, where the objective is to achieve a few predetermined targets.

However, the main advantage of the approach proposed in this paper it is capability to get the benefits of optimization algorithms without available explicit functional representation. The NN is taking over and feeds the optimization model with the needed data. The methodology could be applied to similar situations in quality management and many other fields of social sciences.

7. Discussion and conclusion

Small and medium sized enterprises (SMEs) are the backbone of any economy as 30 – 40% of GDP is contributed by SMEs in any economy. However, their sustainability is challenging due to intense competition and additionally, their environmental and social performances are also not impressive as they require to cut corner everywhere to emphasize on their economic sustainability. Prior researches (e.g. Bourlakis et al. 2014; Dey et al. 2013, Bhattacharya et al. 2015) have proposed several sustainability performance measurement models that enable measure not only individual SMEs sustainability performance but also entire supply chain sustainability performance could be derived. These help both SMEs' owners and managers, and policymakers to suggest improvement measures through standalone performance measurement or benchmarking with the best in the industry and geographical location. However, achieving sustainability through performance measurement has several shortcomings – it could consider a few criteria only, and there are also limitations in number of alternatives being analyzed. On the other hand, there are large number of studies (e.g. Huang et al. 2015) that build relationship using statistical techniques between upstream and downstream criteria for sustainability performance. Additionally, there are researches that reveal characteristics, and issues and challenges of sustainable supply chain practices of SMEs (e.g. Johnson 2015; Govindan et al. 2014; Trianni et al. 2016). They are important to suggest improvement measures to SMEs. However, they are predictive in nature and may not be quite accurate for specific SME. Developing optimal structure of SMEs for achieving sustainability within a geographical location and a specific industry with the consideration of economic, environmental and social criteria help SMEs to achieve sustainability objectively by dynamically measuring their performance and suggesting improvement measures. In summary, the literature on SMEs sustainability covers three broad areas – enhancing sustainability performance of SMEs' supply chain, studies on the impact of various sustainability criteria on business performance, and characteristics of SMEs' supply chain. They are important and significant in furthering knowledge on sustainability performance enhancement of SMEs' supply chain but lack providing holistic measures for improving each SME's sustainability performance objectively. The challenges multiply as the criteria for sustainable supply chain performance measurement is both subjective and objective and conflicting in nature. This requires primary data collection by engaging with representatives of SMEs within a region along with interacting with the policymakers of the specific region. This calls for a new framework of data collection, analysis and interpretation that in one hand develops a diagnostic tool with the consideration of supply chain sustainability practices and performances, and on the other hand derives improvement measures objectively. This research presents a new heuristic using neural network and particle swam optimization model. This enables to derive optimal structure of SMEs within a specific region in line with its business environment. This is beneficial to both policymakers and individual SMEs' owners and managers as both could get information on current state of SMEs' sustainable supply chain and means for improving SMEs' supply chain sustainability. Knowledge on optimal structure of SMEs enables the SME owners to analyze and derive which practices they are likely to enhance or reduce in order to achieve desired optimal sustainability performance (e.g. appropriate combination of turnover, business growth and environmental performance). Optimal structure of SMEs within a region enables policymakers with various information on SMEs practices and performances that leads to achieve greater sustainability. This facilitates them to make budget and other resource allocation decisions within the region that is likely to help achieve greater sustainability of SMEs within that region. Additionally, this helps to benchmark SMEs sustainability performance with the best in the region, which help to implement the best practices from the most appropriate companies.

Theoretically this study contributes a particle swam optimization (PSO) model for sustainability analysis of SMEs through developing optimal sustainability structure of SMEs within a region. According to authors' knowledge, this is the first application of PSO approach in analyzing supply chain sustainability. The proposed model has been applied in two regions of two countries – Normandy in France and Midlands in the UK. The results depict various interesting findings that reveal the robustness of the model in terms of considering varied data, method of data collection, engagement of stakeholders and ability of undertaking sensitivity analysis. In fact, this shows that the model could be used in varied settings in order to improve SMEs sustainability. The proposed model has advantages over the contemporary methods (e.g. conventional MCDM techniques (Dey et al. 2013), DEA approach (Petridis and Dey, 2018) and statistical analysis (Malesios et al. 2018)) with respect to its robustness, objectivity, and possibility of undertaking sensitivity analysis, accuracy, ease to apply and its user friendliness. Additionally, the model is flexible / resilient with an additional feature of incorporating importance of criteria in line with business environment. This enables deriving numerous optimal structure of SMEs as per the business needs allowing both individual SMEs' owners and managers to make decision of SMEs sustainability practices and performance. Also the policymaker's takeaway deep understanding of the issues and challenges of SMEs in their region in order to facilitate overall improvement of sustainability of SMEs within a region.

The proposed method considers multiple objectives along with multiple criteria, which are both subjective and objectives. Data could be collected both from primary and secondary sources using questionnaire survey and conducting interviews. The selection of interviewees (number and experience) is important as the accuracy of the results will depend on this. Various sampling criteria could be chosen to undertake this study in varied regions.

The proposed combined NN and PSO method for sustainable SMEs sustainability structure development has a few shortcomings – considering explicit criteria and sub-criteria, selection of interviewees, considerations of various scenarios (importance of the criteria) and deriving results accordingly, interpreting the results and deciding on improvement measures, convincing all the stakeholders on decisions when the results have been interpreted from various assumptions, and correlating business environment with SMEs' emphasize on sustainability criteria. In view of the above, there are a few scopes of furthering this research through applications in other regions, considering other criteria and sub-criteria, and using different modelling approaches. Additionally, NN and PSO model could be compared with other methods (e.g. conventional MCDM techniques – the AHP and ANP, Fuzzy, Goal Programming, DEA, other statistical methods etc.)

In summary, achieving SMEs' supply chain sustainability is challenging but doable. This requires effort from both policymakers and individual SME owners and managers. Deriving the most appropriate tradeoff among economic, environmental and social criteria could form the optimal structure of SMEs. However, this requires to be dynamic in line with the business environment. Various economic, environmental and social practices could be related to turnover, business growth and environment performance of SMEs to develop a conceptual sustainable structure for SMEs. Data collection on the relationships among practices and performances within a region and running PSO algorithm allows to derive most optimal structure of SMEs within a specific region for different scenarios (e.g. for varied importance on performances criteria – turnover, business growth and environmental performance). This enables to derive improvement measures on SMEs' performance dynamically to achieve greater sustainability.

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Tables

	Observed Outputs			Observed Inputs					Values generated by the NN algorithm		
DMUs	Outp1	Outp2	Outp3	Inp1	Inp2	Inp3	Inp4	Inp5	G.O.1	G.O.2	G.O.3
SME 1 (FR)	4,5	4	3,667	4,000	4,167	3,000	1,700	3,000	4,549	4,087	3,831
SME 2 (FR)	0,5	1	2,000	1,833	4,500	2,667	1,400	2,000	0,519	0,979	2,058
SME 3 (FR)	0,5	1	2,000	1,833	3,167	2,667	1,900	2,000	0,507	0,957	1,927
SME 4 (FR)	3	5	2,000	1,333	4,000	2,667	1,200	2,500	3,042	4,852	2,021
SME 5 (FR)	1	2	3,000	2,167	4,333	2,667	1,800	2,000	1,007	1,993	3,143
SME 6 (FR)	0,5	2	2,000	1,167	3,000	2,667	1,300	1,000	0,509	1,929	1,930
SME 7 (FR)	3	5	4,333	3,833	5,000	3,000	3,300	3,500	2,988	5,000	4,648
SME 8 (FR)	0,5	1	1,333	1,167	1,000	2,000	1,000	1,000	0,523	0,938	1,200
SME 9 (FR)	0,5	1	2,333	2,000	3,167	2,667	2,500	2,000	0,486	0,953	2,291
SME 10 (FR)	0,5	1	2,667	1,833	2,167	2,667	1,800	2,000	0,516	0,947	2,571
SME 11 (FR)	3	1	2,667	1,833	4,167	2,667	1,600	2,000	3,018	0,975	2,766
SME 12 (FR)	0,5	1	2,667	2,167	2,667	2,667	1,800	2,000	0,515	1,001	2,612
SME 13 (FR)	1	2	3,333	3,000	2,000	2,000	3,000	3,000	0,989	1,953	3,250
SME 14 (FR)	2,5	5	4,000	4,000	2,167	2,667	3,200	4,000	2,513	5,000	3,994
SME 15 (FR)	2,5	5	3,667	4,000	3,667	2,667	3,200	4,000	2,505	5,000	3,769
SME 16 (FR)	0,5	1	3,000	3,333	4,833	2,000	3,000	3,000	0,474	1,069	3,147
SME 17 (FR)	0,5	2	3,000	3,333	2,833	2,667	3,000	3,000	0,492	2,038	2,965
SME 18 (FR)	4	1	3,333	3,167	3,500	2,667	3,000	3,000	3,995	1,032	3,403
SME 19 (FR)	0,5	1	2,000	1,833	2,167	2,667	1,400	1,500	0,521	0,993	1,833
SME 20 (FR)	4	2	3,333	3,667	4,500	2,667	3,000	3,000	3,991	2,098	3,489
SME 21(FR)	0,5	1	3,000	2,833	3,833	2,667	1,800	2,500	0,521	1,060	3,079
SME 22 (FR)	1	2	3,333	3,167	3,667	2,667	1,700	2,000	1,018	2,071	3,426
SME 23 (FR)	0,5	3	3,667	3,167	4,333	3,000	2,000	2,000	0,506	3,047	3,866
SME 24 (FR)	0,5	5	3,333	2,167	4,333	2,667	1,800	2,000	0,506	4,950	3,513
SME 25 (FR)	2,5	1	2,667	3,167	2,500	2,667	2,800	3,000	2,505	1,025	2,568
SME 26 (FR)	2	4	4,333	4,500	3,167	3,000	4,000	4,000	1,982	4,075	4,452
SME 27 (FR)	0,5	1	1,333	1,167	1,000	2,000	1,000	1,000	0,523	0,938	1,200
SME 28 (FR)	1,5	2	3,333	3,500	4,667	2,667	3,000	3,000	1,485	2,080	3,509
SME 29 (FR)	0,5	1	2,667	2,833	1,000	2,667	1,600	2,000	0,533	1,078	2,437
SME 30 (FR)	0,5	1	2,333	2,500	2,167	2,667	1,700	2,000	0,522	1,041	2,186
SME 31 (FR)	0,5	1	3,333	3,000	1,667	2,667	1,700	2,000	0,526	1,093	3,236
SME 32 (FR)	0,5	2	2,667	2,833	2,667	2,667	2,900	2,000	0,476	2,038	2,593
SME 33 (FR)	0,5	1	1,667	1,833	3,167	2,667	1,700	1,500	0,505	0,989	1,559
SME 34 (FR)	0,5	2	3,333	3,000	4,000	2,667	3,000	3,000	0,485	2,005	3,456
SME 35 (FR)	3,5	5	3,333	3,167	3,667	2,667	3,000	3,000	3,493	5,000	3,420
SME 36 (FR)	1,5	3	3,667	3,500	2,500	3,000	3,000	3,500	1,509	3,008	3,675
SME 37 (FR)	1	2	3,667	3,333	3,667	3,000	3,200	3,500	0,994	1,998	3,791
SME 38 (FR)	0,5	3	2,000	2,167	3,333	2,667	2,100	1,000	0,481	2,993	1,936
SME 39 (FR)	0,5	1	1,333	1,167	4,333	2,667	1,200	1,000	0,506	0,939	1,318
SME 40 (FR)	1	1	2,000	2,167	4,167	3,000	2,300	1,000	0,974	1,018	2,022
SME 41 (FR)	3,5	5	3,333	3,167	2,833	2,667	3,000	3,000	3,497	4,986	3,339
SME 42 (FR)	0,5	1	1,333	1,167	1,333	2,333	1,200	1,000	0,517	0,936	1,300
SME 43 (FR)	3	3	3,333	3,500	3,167	2,667	2,900	3,000	3,000	3,062	3,364
SME 44 (FR)	0,5	1	3,333	2,833	3,500	3,000	3,000	3,500	0,499	0,918	3,416
SME 45 (FR)	0,5	1	2,667	2,167	5,167	3,000	2,900	4,000	0,500	0,761	2,853
SME 46 (FR)	1	3	4,000	4,000	4,333	3,000	3,900	4,000	0,975	3,026	4,207
SME 47 (FR)	5	1	2,667	2,500	3,833	3,000	1,500	1,000	5,000	1,021	2,726
SME 48 (FR)	5	2	2,333	2,167	5,000	2,667	1,600	1,000	5,000	1,973	2,469
SME 49 (FR)	0,5	1	3,000	2,333	3,333	2,667	3,000	2,500	0,477	0,933	3,037
SME 50 (FR)	0,5	3	3,333	3,167	4,000	2,667	2,700	2,500	0,487	3,054	3,454
SME 51 (FR)	1	3	2,000	1,833	2,500	2,667	1,400	1,500	1,021	2,967	1,865
SME 52 (FR)	0,5	1	2,000	2,333	3,667	3,000	2,300	1,000	0,476	1,034	1,970
SME 53 (FR)	0,5	1	2,667	2,833	2,500	2,667	1,800	3,000	0,537	1,026	2,579
SME 54 (FR)	1,5	1	3,000	3,333	3,333	2,667	2,900	3,000	1,495	1,060	3,014
								MAPE(%)	2,121	3,345	3,682

Table 1. French companies results

Outp1: Turnover, Outp2: Business growth, Outp3: Environmental management, Inp1: Environmental practices, Inp2: Demand management, Inp3: Supply management, Inpu4: Internal process management, Inp5: Social management, G.O.1: Turnover, G.O.2: Business growth and G.O.3: Environmental management. We will use these abbreviations in all tables

	Observed Outputs			Observed Inputs					Values generated by the NN algorithm		
Compagnies	**Outp1**	**Outp2**	**Outp3**	**Inp1**	**Inp2**	**Inp3**	**Inp4**	**Inp5**	**G.O.1**	**G.O.2**	**G.O.3**
SME 1 (UK)	1	1	2,000	1,667	1,000	2,000	1,500	3,000	0,928	0,902	2,003
SME 2 (UK)	1	3	2,000	2,000	2,333	1,667	1,500	2,000	1,017	3,037	1,995
SME 3 (UK)	4	3	2,000	3,000	2,667	4,000	2,500	1,500	3,988	3,085	2,063
SME 4 (UK)	0,5	2	1,000	1,000	1,333	1,667	1,000	1,500	0,472	1,938	0,896
SME 5 (UK)	3	3	1,667	2,667	1,667	1,667	2,500	1,500	3,000	3,053	1,749
SME 6 (UK)	0,5	2	1,333	1,333	1,000	1,667	1,000	1,000	0,461	1,944	1,296
SME 7 (UK)	1,5	1	2,000	2,000	1,000	2,333	1,500	1,500	1,440	0,913	2,047
SME 8 (UK)	2	3	2,000	2,000	2,667	3,000	2,500	2,000	1,997	3,051	1,958
SME 9 (UK)	3	3	2,000	2,000	2,333	2,000	2,500	1,500	3,024	3,042	1,987
SME 10 (UK)	0,5	1	1,667	1,667	1,333	2,333	1,500	2,500	0,437	0,907	1,644
SME 11 (UK)	3	3	2,667	2,000	3,000	2,333	2,000	1,500	3,051	3,049	2,649
SME 12 (UK)	2,5	4	2,000	2,667	2,333	2,667	2,500	2,500	2,488	4,122	2,048
SME 13 (UK)	1	2	2,000	1,667	2,333	2,667	1,500	1,500	0,993	1,975	1,949
SME 14 (UK)	1	3	2,667	1,333	2,667	2,667	1,500	4,000	0,981	3,026	2,571
SME 15 (UK)	1,5	4	1,000	2,000	3,333	2,667	1,500	1,500	1,548	4,109	0,909
SME 16 (UK)	2	3	3,000	2,667	4,000	2,667	1,500	1,500	2,086	3,079	3,026
SME 17 (UK)	1,5	2	1,000	1,667	2,000	3,000	2,000	1,000	1,473	1,975	0,924
SME 18 (UK)	1,5	1	1,333	1,333	2,000	2,333	1,500	1,500	1,491	0,904	1,239
SME 19 (UK)	1,5	4	2,000	2,333	4,000	3,000	2,500	2,500	1,554	4,131	1,936
SME 20 (UK)	4	2	2,000	2,667	2,000	2,667	2,500	2,500	3,983	2,005	2,062
SME 21(UK)	0,5	1	1,000	1,333	2,667	1,333	1,000	1,500	0,550	0,905	0,881
SME 22 (UK)	1	2	1,667	2,000	3,000	2,333	1,500	1,500	1,037	1,991	1,617
SME 23 (UK)	0,5	3	1,000	1,000	2,000	1,667	1,500	1,000	0,509	3,003	0,868
SME 24 (UK)	1	2	1,000	1,333	1,000	2,000	1,500	1,500	0,946	1,948	0,940
SME 25 (UK)	2	1	2,000	2,333	2,333	2,333	1,500	1,500	2,011	0,937	2,028
SME 26 (UK)	0,5	2	1,333	1,000	1,000	1,000	1,000	1,500	0,475	1,931	1,263
SME 27 (UK)	4,5	5	3,000	3,333	3,000	3,333	3,000	3,000	4,509	5,000	3,115
SME 28 (UK)	1,5	2	2,000	1,667	2,333	2,667	2,000	2,500	1,483	1,977	1,939
SME 29 (UK)	2	3	3,000	2,333	3,000	2,333	1,500	2,000	2,039	3,057	3,031
SME 30 (UK)	0,5	1	2,667	2,000	1,667	1,667	2,000	2,000	0,477	0,919	2,709
							MAPE(%)		3,11	3,56	3,95

Table 2. UK companies results

	Observed Outputs			Observed Inputs					Values generated by the NN algorithm		
Compagnies	**Outp1**	**Outp2**	**Outp3**	**Inp1**	**Inp2**	**Inp3**	**Inp4**	**Inp5**	**G.O.1**	**G.O.2**	**G.O.3**
SME 1 (UK)	1	1	2,000	1,667	1,000	2,000	1,500	3,000	0,998	0,990	1,999
SME 2 (UK)	1	3	2,000	2,000	2,333	1,667	1,500	2,000	1,009	2,996	1,992
SME 3 (UK)	4	3	2,000	3,000	2,667	4,000	2,500	1,500	3,997	2,996	2,016
SME 4 (UK)	0,5	2	1,000	1,000	1,333	1,667	1,000	1,500	0,500	2,007	0,990
SME 5 (UK)	3	3	1,667	2,667	1,667	1,667	2,500	1,500	3,033	2,976	1,703
SME 6 (UK)	0,5	2	1,333	1,333	1,000	1,667	1,000	1,000	0,518	1,998	1,383
SME 7 (UK)	1,5	1	2,000	2,000	1,000	2,333	1,500	1,500	1,517	0,988	2,075
SME 8 (UK)	2	3	2,000	2,000	2,667	3,000	2,500	2,000	1,987	3,012	1,979
SME 9 (UK)	3	3	2,000	2,000	2,333	2,000	2,500	1,500	3,005	3,000	2,012
SME 10 (UK)	0,5	1	1,667	1,667	1,333	2,333	1,500	2,500	0,498	0,997	1,660
SME 11 (UK)	3	3	2,667	2,000	3,000	2,333	2,000	1,500	2,992	3,007	2,682
SME 12 (UK)	2,5	4	2,000	2,667	2,333	2,667	2,500	2,500	2,505	3,995	1,985
SME 13 (UK)	1	2	2,000	1,667	2,333	2,667	1,500	1,500	0,993	2,009	2,010
SME 14 (UK)	1	3	2,667	1,333	2,667	2,667	1,500	4,000	0,952	3,013	2,569
SME 15 (UK)	1,5	4	1,000	2,000	3,333	2,667	1,500	1,500	1,489	4,013	0,922
SME 16 (UK)	2	3	3,000	2,667	4,000	2,667	1,500	1,500	1,998	2,999	2,998
SME 17 (UK)	1,5	2	1,000	1,667	2,000	3,000	2,000	1,000	1,498	2,011	0,997
SME 18 (UK)	1,5	1	1,333	1,333	2,000	2,333	1,500	1,500	1,490	1,009	1,318
SME 19 (UK)	1,5	4	2,000	2,333	4,000	3,000	2,500	2,500	1,478	4,016	1,904
SME 20 (UK)	4	2	2,000	2,667	2,000	2,667	2,500	2,500	4,002	1,988	2,000
SME 21(UK)	0,5	1	1,000	1,333	2,667	1,333	1,000	1,500	0,499	1,003	0,937
SME 22 (UK)	1	2	1,667	2,000	3,000	2,333	1,500	1,500	0,999	2,003	1,635
SME 23 (UK)	0,5	3	1,000	1,000	2,000	1,667	1,500	1,000	0,502	3,016	0,982
SME 24 (UK)	1	2	1,000	1,333	1,000	2,000	1,500	1,500	1,007	2,002	1,013
SME 25 (UK)	2	1	2,000	2,333	2,333	2,333	1,500	1,500	2,010	0,989	2,020
SME 26 (UK)	0,5	2	1,333	1,000	1,000	1,000	1,000	1,500	0,512	1,999	1,352
SME 27 (UK)	4,5	5	3,000	3,333	3,000	3,333	3,000	3,000	4,495	4,994	2,994
SME 28 (UK)	1,5	2	2,000	1,667	2,333	2,667	2,000	2,500	1,481	2,010	1,966
SME 29 (UK)	2	3	3,000	2,333	3,000	2,333	1,500	2,000	1,998	2,998	3,018
SME 30 (UK)	0,5	1	2,667	2,000	1,667	1,667	2,000	2,000	0,519	0,988	2,721
SME 1 (FR)	4,5	4	3,667	4,000	4,167	3,000	1,700	3,000	4,503	3,977	3,653
SME 2 (FR)	0,5	1	2,000	1,833	4,500	2,667	1,400	2,000	0,471	1,016	1,895
SME 3 (FR)	0,5	1	2,000	1,833	3,167	2,667	1,900	2,000	0,487	1,009	1,954
SME 4 (FR)	3	5	2,000	1,333	4,000	2,667	1,200	2,500	2,945	5,000	1,886
SME 5 (FR)	1	2	3,000	2,167	4,333	2,667	1,800	2,000	0,981	2,012	2,955
SME 6 (FR)	0,5	2	2,000	1,167	3,000	2,667	1,300	1,000	0,482	2,024	1,991
SME 7 (FR)	3	5	4,333	3,833	5,000	3,000	3,300	3,500	2,996	5,000	4,286
SME 8 (FR)	0,5	1	1,333	1,167	1,000	2,000	1,000	1,000	0,510	1,002	1,381
SME 9 (FR)	0,5	1	2,333	2,000	3,167	2,667	2,500	2,000	0,493	1,007	2,305

SME 10 (FR)	0,5	1	2,667	1,833	2,167	2,667	1,800	2,000	0,496	1,003	2,698
SME 11 (FR)	3	1	2,667	1,833	4,167	2,667	1,600	2,000	2,964	1,015	2,608
SME 12 (FR)	0,5	1	2,667	2,167	2,667	2,667	1,800	2,000	0,500	0,999	2,681
SME 13 (FR)	1	2	3,333	3,000	2,000	2,000	3,000	3,000	1,029	1,976	3,380
SME 14 (FR)	2,5	5	4,000	4,000	2,167	2,667	3,200	4,000	2,532	4,970	4,050
SME 15 (FR)	2,5	5	3,667	4,000	3,667	2,667	3,200	4,000	2,517	4,979	3,632
SME 16 (FR)	0,5	1	3,000	3,333	4,833	2,000	3,000	3,000	0,511	0,983	2,907
SME 17 (FR)	0,5	2	3,000	3,333	2,833	2,667	3,000	3,000	0,523	1,979	3,000
SME 18 (FR)	4	1	3,333	3,167	3,500	2,667	3,000	3,000	3,997	0,985	3,316
SME 19 (FR)	0,5	1	2,000	1,833	2,167	2,667	1,400	1,500	0,501	1,002	2,020
SME 20 (FR)	4	2	3,333	3,667	4,500	2,667	3,000	3,000	4,000	1,981	3,277
SME 21(FR)	0,5	1	3,000	2,833	3,833	2,667	1,800	2,500	0,500	0,991	2,969
SME 22 (FR)	1	2	3,333	3,167	3,667	2,667	1,700	2,000	1,014	1,984	3,350
SME 23 (FR)	0,5	3	3,667	3,167	4,333	3,000	2,000	2,000	0,506	2,994	3,669
SME 24 (FR)	0,5	5	3,333	2,167	4,333	2,667	1,800	2,000	0,483	5,000	3,304
SME 25 (FR)	2,5	1	2,667	3,167	2,500	2,667	2,800	3,000	2,513	0,978	2,664
SME 26 (FR)	2	4	4,333	4,500	3,167	3,000	4,000	4,000	2,036	3,965	4,359
SME 27 (FR)	0,5	1	1,333	1,167	1,000	2,000	1,000	1,000	0,510	1,002	1,381
SME 28 (FR)	1,5	2	3,333	3,500	4,667	2,667	3,000	3,000	1,504	1,986	3,267
SME 29 (FR)	0,5	1	2,667	2,833	1,000	2,667	1,600	2,000	0,534	0,973	2,770
SME 30 (FR)	0,5	1	2,333	2,500	2,167	2,667	1,700	2,000	0,514	0,988	2,360
SME 31 (FR)	0,5	1	3,333	3,000	1,667	2,667	1,700	2,000	0,532	0,973	3,440
SME 32 (FR)	0,5	2	2,667	2,833	2,667	2,667	2,900	2,000	0,521	1,987	2,689
SME 33 (FR)	0,5	1	1,667	1,833	3,167	2,667	1,700	1,500	0,492	1,009	1,625
SME 34 (FR)	0,5	2	3,333	3,000	4,000	2,667	3,000	3,000	0,502	1,994	3,290
SME 35 (FR)	3,5	5	3,333	3,167	3,667	2,667	3,000	3,000	3,497	5,000	3,308
SME 36 (FR)	1,5	3	3,667	3,500	2,500	3,000	3,000	3,500	1,518	2,980	3,698
SME 37 (FR)	1	2	3,667	3,333	3,667	3,000	3,200	3,500	1,004	1,989	3,642
SME 38 (FR)	0,5	3	2,000	2,167	3,333	2,667	2,100	1,000	0,506	3,006	1,990
SME 39 (FR)	0,5	1	1,333	1,167	4,333	2,667	1,200	1,000	0,468	1,030	1,233
SME 40 (FR)	1	1	2,000	2,167	4,167	3,000	2,300	1,000	0,992	1,010	1,951
SME 41 (FR)	3,5	5	3,333	3,167	2,833	2,667	3,000	3,000	3,506	4,991	3,347
SME 42 (FR)	0,5	1	1,333	1,167	1,333	2,333	1,200	1,000	0,503	1,008	1,367
SME 43 (FR)	3	3	3,333	3,500	3,167	2,667	2,900	3,000	3,013	2,980	3,337
SME 44 (FR)	0,5	1	3,333	2,833	3,500	3,000	3,000	3,500	0,493	0,996	3,291
SME 45 (FR)	0,5	1	2,667	2,167	5,167	3,000	2,900	4,000	0,451	1,018	2,486
SME 46 (FR)	1	3	4,000	4,000	4,333	3,000	3,900	4,000	1,013	2,982	3,949
SME 47 (FR)	5	1	2,667	2,500	3,833	3,000	1,500	1,000	4,983	0,998	2,673
SME 48 (FR)	5	2	2,333	2,167	5,000	2,667	1,600	1,000	4,967	2,014	2,264
SME 49 (FR)	0,5	1	3,000	2,333	3,333	2,667	3,000	2,500	0,496	1,002	2,981
SME 50 (FR)	0,5	3	3,333	3,167	4,000	2,667	2,700	2,500	0,510	2,991	3,313
SME 51 (FR)	1	3	2,000	1,833	2,500	2,667	1,400	1,500	0,995	3,009	2,005
SME 52 (FR)	0,5	1	2,000	2,333	3,667	3,000	2,300	1,000	0,504	1,003	1,976
SME 53 (FR)	0,5	1	2,667	2,833	2,500	2,667	1,800	3,000	0,509	0,983	2,659
SME 54 (FR)	1,5	1	3,000	3,333	3,333	2,667	2,900	3,000	1,513	0,980	2,977
MAPE (%)									1,476	0,686	1,676

Table 3. UK & French companies results

	Inp1	Inp2	Inp3	Inp4	Inp5	Outp1.Opt	Outp2.Opt	Outp3.Opt	Opt.Sol
(0,2 ; 0,3 ; 0,5)	3,54	1	2,59	1	4	2,711	1,697	3,497	2,7998
(0,25 ; 0,6 ; 0,15)	4,5	1	2	1	4	1,835	2,615	1,745	2,2895
(0,3 ; 0,25 ; 0,45)	4,5	1	2,93	1	4	1,644	1,583	1,694	1,65125
(0,4 ; 0,5 ;0,1)	4,5	5,167	2,985	3,501	2,84	2,607	2,322	2,855	2,4893
(0,45 ; 0,2 ;0,35)	4,5	4,708	2,78	1,33	3	3,682	3,041	2,102	3,0008
(0,8 ;0,1 ;0,1)	1,167	5,167	2	4	4	2,223	2,316	3,123	2,3223
(0,1 ;0,8;0,1)	4,5	1	3	4	1	2,918	3,178	3,131	3,1473
(0,1 ;0,1 ;0,8)	1,167	5,167	2,996	1	3,195	1,115	3,483	3,783	3,4862

Table 4, Optimal solutions for different weights ω_k ($M = 5$) – French companies

Outp1,Opt: Turnover Optimal value, Outp2,Opt: Business growth Optimal value Outp3,Opt: Environmental management Optimal value, Opt,Sol: Optimal solution. We will use these abbreviations in the two next tables

	Inp1	Inp2	Inp3	Inp4	Inp5	Outp1,Opt	Outp2,Opt	Outp3,Opt	Opt,Sol
(0,2 ; 0,3 ; 0,5)	1	4	1	1,801	3,031	2,023	2,553	1,702	2,0215
(0,25 ; 0,6 ; 0,15)	1	4	1	3	1	3,863	1,141	1,654	1,89845
(0,3 ; 0,25 ; 0,45)	3,333	1	4	2,95	1	3,949	2,453	2,008	2,70155
(0,4 ; 0,5 ;0,1)	3,333	2,828	1	1	4	3,173	3,023	3,404	3,1211
(0,45 ; 0,2 ;0,35)	1	4	4	1,029	1	2,342	1,89	1,537	1,96985
(0,8 ;0,1 ;0,1)	1	4	2,157	1	4	2,011	2,034	4,189	2,34575
(0,1 ;0,8;0,1)	3,333	1	1	3	1	4,742	4,056	4,136	4,6128
(0,1 ;0,1 ;0,8)	1	3,972	1	3	4	2,83	1,694	2,574	1,8956

Table 5, Optimal solutions for different weights ω_k $(M = 5)$ – UK companies

	Inp1	Inp2	Inp3	Inp4	Inp5	Outp1,Opt	Outp2,Opt	Outp3,Opt	Opt,Sol
(0,2 ; 0,3 ; 0,5)	4,5	1	4	1	4	3,811	2,496	1,186	2,104
(0,25 ; 0,6 ; 0,15)	1	5,167	1	4	1	1,525	1,86	2,224	1,830
(0,3 ; 0,25 ; 0,45)	1	3,683	4	1	1	4,282	1,425	1,836	2,467
(0,4 ; 0,5 ;0,1)	1	5,167	4	1	3,565	3,832	3,136	1,852	3,286
(0,45 ; 0,2 ;0,35)	4,5	5,167	1	1	4	3,278	3,062	2,419	2,93
(0,8 ;0,1 ;0,1)	1	5,0827	1	4	4	2,867	2,746	1,798	2,748
(0,1 ;0,8;0,1)	1	1	2,008	4	4	2,029	1,811	1,858	1,8375
(0,1 ;0,1 ;0,8)	3,609	1	1	2,861	4	2,745	3,259	2,774	2,8196

Table 6, Optimal solutions for different weights ω_k $(M = 5)$ – UK & French companies

Criteria	Inp1	Inp2	Inp3	Inp4	Inp5	Outp1	Outp2	Outp3
Observed data of specific SME	3,167	3,667	2,667	3,000	3,000	3,5	5	3,333
Optimum results	3,54	1	2,59	1	4	2,711	1,697	3,497
Improvement measures	Slightly improvement in environmental practices	Substantial reduction of resources from demand management	Keeping supply management as is	Substantial reduction of attention on internal processes	Improvement in social management activities	Turnover will go down	Business growth is likely to reduce	The concerned SME is likely to reflect enhancement in environmental performance

Table 7a: Deriving means for improvement (FR)

Criteria	Inp1	Inp2	Inp3	Inp4	Inp5	Outp1	Outp2	Outp3
Observed data of specific SME	3,167	3,667	2,667	3,000	3,000	3,5	5	3,333
Optimum results	1.167	5.167	2.996	1	3.195	1.115	3.483	3,783
Improvement measures	Reduction of environmental practices	Substantial improvement of resources from demand management	Slightly improving supply management	Less attention to internal processes	slight improvement in social management activities	Turnover will go down substantially	Business growth is likely to reduce	The concerned SME is likely to reflect enhancement in environmental performance

Table 7b: Deriving means for improvement (FR) for achieving optimal sustainability

Criteria	Inp1	Inp2	Inp3	Inp4	Inp5	Outp1	Outp2	Outp3
Observed data of specific SME	3,000	2,667	4,000	2,500	1,500	4	3	2,000
Optimum results	1	4	1	1,801	3,031	2,023	2,553	1,702
Improvement measures	Substantial reducing in environmental practices	Slightly improvement in demand management	Substantial reducing resources from supply management	Substantial reducing in internal processes	Substantial improvement in social management activities	Turnover will go down	Business growth is likely to reduce	The concerned SME is likely to reflect enhancement in environmental performance

Table 8a: Deriving means for improvement (UK)

Criteria	Inp1	Inp2	Inp3	Inp4	Inp5	Outp1	Outp2	Outp3
Observed data of specific SME	3,000	2,667	4,000	2,500	1,500	4	3	2,000
Optimum results	3.333	1	1	3	1	4.742	4.056	4.136
Improvement measures	Improving environmental practices	Slightly reducing demand management	Substantial reducing resources from supply management	Improving internal processes	Slightly reducing social management activities	Turnover is likely to enhance	Business growth is likely to enhance	The concerned SME is likely to reflect enhancement in environmental performance

Table 8b: Deriving means for improvement (UK) for optimal sustainability

APPENDIX A

Small and Medium Enterprises (SMEs) Sustainability Structure

The objective of this study is to derive sustainability performance of SMEs and suggest improvement measures through benchmarking with most appropriate SMEs, Each participating SME will be informed through formal report on their performance and means for improvement,

Personal Information (optional):

Name: Contact: Company:

Telephone: Email:

Please tick at the appropriate place:

1. Brief description of the company:

a) Location(State): East North South West Central

b) Industry type: Manufacturing Process Service Construction R&D Pharmaceuticals Others(Please specify)

c) Major products/services:

d) Business Start Year:

e) Turnover (in Rupees): Below 10lakh 10 – 25lakh 25 – 50lakh Above 50lakh

f) Growth in last 5 years: 0% – 10% 10% – 30% 30% – 50% Above 50%

g) Number of employees: 5-10 10-50 50 – 100100 – 250 Above 250

h) Growth in employee number: 0% – 10% 10% – 30% 30% – 50% Above 50%

i) Major customers: OEMs Retailers End-customers National International PSUs Others(Please specify)

j) Percentage of international customers: 0% – 10% 10% – 30% 30% – 50% Above 50%

k) Major suppliers: Steel Manufactures Component Manufacturers Chemical Processing Companies Others(Please specify)

Supply chain issues and challenges:

How much would you rate on a scale of 1-5: 5=Very high, 4=High, 3=Medium, 2=Low and 1=Not at all

2. Do you face supply uncertainty: 5 4 3 2 1
3. Do you face demand uncertainty: 5 4 3 2 1
4. Do you face internal operational uncertainty: 5 4 3 2 1
5. Do you face cash flow issues : 5 4 3 2 1
6. Do you feel customers drives your environmental and social practices 5 4 3 2 1
7. Do you feel Government drives your environmental and social practices 5 4 3 2 1
8. Do you feel there is a communication issue within the organisation 5 4 3 2 1
9. Do you feel there is an issue with leadership within the organisation 5 4 3 2 1
10. Do you feel there is an issue with middle level management within the organisation 5 4 3 2 1

11. Do you feel there is an issue with workmen within the organisation 5 4 3 2 1

Criteria	Practices		Performances	
	5=100%,4=99 –50%,3=49% - 20%, 2=Less than 20%, 1=Not adopted at all		*5=Very high, 4=High, 3=Medium, 2=Low and 1=Not adopted at all*	
SRM	Percentage of suppliers with whom you have long term relationship?		How effective is supplier relationship management?	
CRM	Percentage of customer with whom you have long term relationship?		How effective is customer relationship management?	
Capacity Utilisation	Percentage of capacity utilisation practices?		How effective is capacity utilisation?	
Forecasting Demand	Percentage of forecasting error?		How effective is your demand forecasting?	
	5=Very high, 4=High, 3=Medium, 2=Low and 1=Not adopted at all			
Production Planning	Do you have Production Planning practices?		How effective is your Production Planning practices?	
Quality Management System	Have you adopted ISO 9000?		How effective is ISO 9000?	
Environment Management System	Have you adopted ISO 14000 / Environment Management System?		How effective is your Environmental Management System?	
Chartered Quality Institute	Have you adopted CQI?		How effective is CQI?	
Lean approach	Have you adopted formal lean approach in manufacturing?		How effective is your formal lean approach in manufacturing?	
Raw Material Inventory	Have you adopted raw material inventory policy?		How effective is your raw material inventory policy?	
Finished Product Inventory	Have you adopted finished product inventory policy?		How effective is your finished product inventory policy?	
Work in progress (WIP)	Do you have high WIP?		How effective is your WIP?	
Formal Risk Management	Have you adopted any formal risk management method in your production and operations management?		How effective is your risk management?	
Maintenance Policy	Have you adopted Maintenance Policy?		How effective is your Maintenance Policy?	
Waste Management	Have you adopted any formal waste management policy?		How effective is your waste management?	
Reverse logistics policy	Have you adopted reverse logistics policy?		How effective is your reverse logistics policy?	
Emissions Control	Do you adopt practices to reduce emission control?		How effective is your emission control?	
Energy Efficiency Program	Have you adopted energy efficiency program?		How effective is your energy efficiency program?	
Social Health and Occupational Hazard	Have you adopted social health and occupational hazard practice?		How effective is your social health and occupational hazard practice?	
Training for employee	Do you provide training for employee?		How effective is training for employee?	
Employee Welfare	Do you adopt employee welfare practices?		How effective is employee welfare practices?	