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INDICATORS AND METHODS FOR ENVIRONMENTALLY CONSCIOUS MANUFACTURING PROGRAMMES: A REVIEW AND REFLECTIONS

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Abstract: *In recent times, because of climate change and other negative consequences of environmental impact of manufacturing activities, environmentally conscious manufacturing (ECM) programme has emerged as one of the most important aspects and a proactive approach for improving sustainable performance of products and processes in majority of the manufacturing organizations requiring a total approach capable of addressing multiple dimensions of environmental management. Several indicators and methods for ECM have already been proposed by different researchers and practitioners from all over the world during the last few decades. Hence, a review of those indicators and methods may be considered a prime necessity so that the manufacturing organizations may easily select the appropriate methods to improve and sustain their environmental performance. In this paper, the application potential of several indicators and methods for ECM has been classified and the methods have been critically appraised highlighting their merits and limitations. Thereafter, a comprehensive, integrated and holistic generic research framework is proposed with different analysis and modelling techniques. The inherent characteristic features and the selection norms of these techniques are mentioned. Four different research issues are also addressed in the conclusions section. This paper will help the manufacturing organizations to develop their environmental management system (EMS).*

Keywords: *Climate Change; Environmentally Conscious Manufacturing (ECM) Programmes; Environmental Management; Manufacturing Organizations; Environmental Management System (EMS)*

1. INTRODUCTION

Environmental performance measurement and evaluation has been the focus of considerable attention over the past few decades. The evaluation of environmentally conscious manufacturing (ECM) programme is similar to many strategic initiatives and their justification methodologies (Sarkis, 1999) to gain sustainability in manufacturing which is becoming increasingly important to business research and practice over the last few decades as a result of rapid

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depletion of natural resources and concerns over wealth disparity and corporate social responsibility (Dao *et al.*, 2011). By designing environment-friendly products and processes, any business organization may generate benefits to the environment by reducing waste and emission to air with proper utilization of resources, in order to achieve economic benefits (Eltayeb *et al.*, 2011). Environment-friendly manufacturing, considered as a vital part of any business or non-business, may also result in preventing of global warming and climate change in the long term by reducing the carbon footprint which is a measure of the total amount of carbon dioxide (CO_2) and methane (CH_4) emissions of a defined population, system or activity, taking into account all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest as defined by Wright *et al.* (2011) (Gaussin *et al.*, 2012). To achieve environment friendly manufacturing, development of an appropriate environmental management system (EMS) may be considered as essential. With the globalization of the economy, any manufacturing organization may be required to develop or upgrade their EMS conforming to international standards, with the objective of improving environmental performance by controlling emissions and effluents and reducing environmental impacts (Chen, 2005). In many instances, a comprehensive and integrated management system is essential to make EMS effective for meeting varied requirements including legal and policy aspects (Kruger, 2005; ISO 14001 (2004)).

With today's global awareness of environmental risks, manufacturing systems are evolving into a new paradigm which may be termed as green manufacturing (GM) that employs various environment-friendly strategies and techniques in order to become more eco-efficient. In this context, the concept of green supply chain management (GSCM) has also emerged as an organization-wide philosophy to reduce environmental risks associated to environmental pollution (Deif, 2011; Diabat and Govindan, 2011). GSCM may be considered an important approach to reduce environmental risks, with corresponding economic benefit to manufacturers (Lin *et al.*, 2011). To improve both economic and environmental performance simultaneously throughout supply chains, green manufacturing firms are helping the manufacturing organizations to purchase environmentally superior products to build environmental practices and operational efficiencies (Cheng and Sheu, 2012). Global and domestic environmental laws, rules and regulations are forcing many organizations to adopt both green manufacturing and green supply chain management framework considering 'reduce-recycling-reuse' (3R) of resources as well as reducing or minimizing environmental impacts of all functions, business processes and products (Jayal *et al.*, 2010; Sarkis 1995).

There have been a large number of indicators and methods developed for ECM programmes. Most of the approaches are essentially based on empirical research study and in varieties of environmental management-related issues as applicable in manufacturing organization. However, listing of these indicators (termed as environmental performance indicators or EPI) and methods has not been done previously by the researchers. Hence, the present paper sets itself the following three objectives in the context of ECM programmes:

1. Classification of the existing indicators and methods for ECM programmes,
2. Critical appraisal of the existing methods with their characteristic features, merits and limitations, and
3. A comprehensive and integrated generic framework to evaluate ECM programmes

Rest of the paper is organized as follows. Importance of the ECM programmes is provided in section 2. Classification of the existing methods for ECM programmes is described with the corresponding indicators in section 3. Critical appraisal of the existing methods is discussed in section 4. A generic framework is proposed in section 5. The conclusions part is given in section 6.

2. IMPORTANCE OF THE ECM PROGRAMMES

The most important broad objective of ECM programmes is to control the climate change as temperatures are on the rise all around the globe resulting into the number of extremely hot days to dramatically increase in the future. There is scientific evidence that the change in climate worldwide is a real problem leading to global warming as has been found by several researchers (Gutowski *et al.*, 2005; Swain, 2006; Pizer *et al.*, 2011; Marshall *et al.*, 2013). The changes in climate are related to increases in concentration of greenhouse gases (GHG) in the atmosphere, trapping infrared radiation close to the Earth's surface. Many kinds of human activities may have contributed to increase the level of these gases. Industries, in general and manufacturing, in particular, contribute significantly to the GHG emission. As a result of global warming, sea levels are rising, glaciers are retreating, polar ice caps are melting, and the number and severity of extreme weather events are gradually increasing. In light of these events and their anticipated impacts in future, it is essential to reduce the emissions of GHG (Report of the Canadian Chamber of Commerce 2006; Gutowski *et al.* 2005). Pizer *et al.* (2011) while conducting a study to assess environmental effectiveness of the industrial sector elements of climate change programmes in industrial sector, Rehan and Nehdi (2005) examine some of the traditional and emerging policy instruments for greenhouse gas emissions to analyse their merits and drawbacks before suggesting a model called renewable portfolio standard (RPS) dealing with the applicability, effectiveness and potential impact of the policy instruments with recommendations for possible courses of action. Zeng *et al.* (2009) propose four specific approaches namely (i) clean development mechanism (CDM) projects, (ii) technology for GHG reduction, (iii) social responsibility-based voluntary carbon market (VCM) and (iv) energy auditing in order to design the economic factors and incentive mechanisms.

From enterprises' point of view, Marshall *et al.* (2013) consider the importance of ECM on the basis of four essential dimensions: (i) management of risk and uncertainty, (ii) skills in planning, learning and reorganising, (iii) financial and emotional flexibility and (iv) interest in adapting. There are a number of good reasons to take action on climate change from the enterprises' perspective, such as to reduce cost and increase revenue, reducing the risks associated with higher energy costs. Appropriate strategies may be developed for reduction of greenhouse gas emissions by means of preventive and corrective measures, wherever feasible as with compliance with government-initiated regulations (Niemeijer, 2002; Report of the Erdman Center, 2004; Swain, 2006; Oda *et al.*, 2012). To address climate change issues with increasing environmental performance, a number of policies and measures, such as economic restructuring, energy efficiency improvement, development and utilization of hydropower and other renewable energy, ecological restoration and protection practices may be required, as has been reported by a number of countries (National Development and Reform Commission, People's Republic of China (June, 2007)). However, the cost of addressing the effect of climate change aspect may not be unaffordable in many cases (Vivid Economics, October 2006). Hence, factors such as weather patterns, water resources, season cycles, ecosystems, and extreme climate events need to be addressed simultaneously in order to make an ECM programme successful.

From product's point of view, relevant environmental aspects need to be considered not only for manufacturing processes being used for production, but also for its entire supply chain, from its suppliers to its customers. All sorts of activities being carried out within the supply chain of the product may have an interaction with environmental issues directly or indirectly (Klassen and Angell, 1998; Madu and Madu, 2002; Chen, 2005). Changing product design or processing methods may bring significant effect on energy consumption and/or waste generation or environmental pollution influencing the economic performance of a manufacturing system, such as cost, yield, quality, and customer service. The trade-off between economic and environmental benefits has made the innovation in cleaner production a challenging task faced by the manufacturing, impacting on not only enterprises' operations management but also strategic planning (Zhou *et al.*, 2012). To execute an ECM programme, the factors that may have short and long-term implications on the environment as well as business strategies in the long-term are required to be considered (Sarkis 1999).

3. CLASSIFICATION OF THE EXISTING METHODS FOR ECM PROGRAMMES

There exist a large number of indicators and methods for ECM developed by the researchers and practitioners over the years. Any manufacturing organization can use all the indicators mentioned in this paper to develop their EMS, however selection of the indicators may depend on their specific environmental problems. Hence, a generic framework is also proposed considering the significance level and interrelationships among different environmentally conscious manufacturing indicators (ECMI). If any specific indicator is not relevant or important for a particular manufacturing organization, it may get less scale-value and the results obtained from the generic framework will be influenced accordingly. The ECMIs proposed by the researchers are either at strategic levels (i.e. environmental proactivity) or operational (manufacturing and non-manufacturing based) levels. Hence, ECM programmes may be broadly classified in three ways, namely, environmental proactivity (EP) manufacturing based operational performance (MOP) and non-manufacturing based operational Performance (NOP).

3.1. Environmental Proactivity (EP)

Environmental proactivity (EP) basically deals with various strategic levels environmental decision making of an ECM programme. Under this category, there are five methods, namely, (i) Strategic Environmental Assessment (SEA), (ii) Sustainability Measurement (SM), (iii) Intelligent Environmental Management (IEM), (iv) Environmental Innovation Management (EIM) and (v) Environmental Risk Governance (ERG).

(i) Strategic Environmental Assessment (SEA)

It has been discussed critically in several literature that strategic environmental assessment (SEA) is a vital approach to focus on ECM programmes. For quantitative evaluation of product design, an assessment model for manufacturing processes in terms of environmental impact may be considered a prime necessity. Thus, multiple factors need to be considered for SEA, most of which have long-term and broad implications for an organization. SEA may depend on top management support/commitment and manpower involvement including environmental training (Toke *et al.*, 2012; Sambasivan *et al.*, 2013; Jabbour *et al.*, 2013).

SEA focuses on the environmental expenditure like operational cost, training cost, environment friendly materials cost, waste and water treatment/recycling cost. In order to be successful, environmental management strategies including environmental expenditure should be integrated into all stages of the value chain, which including processes planning, product design, procurement, manufacturing and assembly, packaging, logistics, and distribution (Sueyoshi and Goto, 2009; Jaraite *et al.*, 2012; Wang *et al.*, 2014).

SEA may approach to maintain regulations imposed by the government and stakeholders. According to Choi *et al.* (1997) develop an assessment methodology on the basis of the 'material balance' of a process with a case study to illustrate and examine the assessment model showing that the number of components, the selection of materials and processes, and recyclability are the essential factors to meet the demand of the stakeholders and maintain the rules imposed by the government. Eiadat *et al.* (2008) present how strategic environmental decision is influenced by stakeholders' pressures, including government environmental regulations.

SEA may consider to have ISO 14001 certification or environmental policy or formal environmental management system (EMS) to evaluate quantitative data including managerial preferences for the purpose of selecting an environmentally conscious manufacturing (ECM) program (Sarkis, 1999; Jabbour *et al.*, 2013; Toke *et al.*, 2012).

SEA also may approach to have total quality management (TQM) system/ISO 9001 certification. The number of organizations contemplating the integration of quality practices like ISO 9001 certification is continuously increasing into their strategic environmental plans and daily operations. Though TQM/ISO 9001 basically focuses on conformance which is the degree to which a product characteristic meets preset standards, however this may also lead to improve the environmental quality of the processes and products through standardization, statistical quality control (SQC) and inspection. For example, in many a cases, a robust system can minimize the amount of wastes, improving the overall environmental performance (Casadesús *et al.*, 2008; Zhu *et al.*, 2013; Terziovski *et al.*, 2003).

(ii) Sustainability Measurement (SM)

Achieving long term 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. This requires improved models, metrics for sustainability evaluation, and optimization techniques at the product, process, and system levels (Toke *et al.*, 2012; Sambasivan *et al.*, 2013). Joung *et al.* (2012) categorize of sustainability indicators, based on mutual similarity, in five dimensions of sustainability such as environmental stewardship, economic growth, social well-being, technological advancement, and performance management; explaining how to use the indicators to assess a company's manufacturing operations. Thus, long term sustainable initiative over budget schedule may be required by the manufacturing organizations to execute ECM programmes.

Recycling initiatives may be considered an important dimension to achieve sustainability. Ricoh Group Sustainability Report (2007) proposes Comet Circle to represent a sustainable society that recirculates resources. The development of a recycling-based society may be achieved by focusing on five activities namely identifying and reducing environmental impact at all stages, putting priority on inner loop recycling stages, promoting a multi-tired recycling system, more economically rational recycling, and establishing a partnership at every stage. Despeisse *et al.* (2012) present a tactics library to provide a connection between generic sustainability concepts and more specific examples of operational practices for resource efficiency in factories in order to improve sustainability in a structured, systematic and cross-functional way.

(iii) Intelligent Environmental Management (IEM)

Intelligent environmental management (IEM) deals with computer/software based environmental management or communication management to exchange green initiatives among similar sectors. Burke and Gaughran (2006) develop a multi-leveled Intelligent Environmental Management (IEM) system named as 'n-tier architecture' to provide a holistic scenario for large scale manufacturing organizations, basically. Butler (2011) suggests an ICBA named as 'Green Information System' to take environment-friendly initiatives in organisational sense-making, decision making, knowledge sharing and green design with the objective of identifying problems and opportunities, closing knowledge gaps, and leveraging learning outcomes. In order to reduce damage to the environment, Kuo *et al.* (2012) present a process-based reference model and information system to manage and control the quantity and quality of the supply network. Describing the overall operational workflow, an object-oriented, analytical approach is used to represent the architecture of the collaborative model in order to demonstrate the effectiveness of the model in controlling the supply network of materials with improved communications. While Dao *et al.* (2011) develop an integrated framework, integrating human, supply chain, and IT resources, Giovannini *et al.* (2012) propose a product centric ontology, in which concepts of product, processes and resources are associated to functions of manufacturing knowledge in order to design a knowledge-based system which is able to automatically identify change opportunities and can propose alternatives on the basis of the existing production scenario. However, IEM may not be suitable for SMEs as the software required to communicate environmental information may be costly.

(iv) Environmental Innovation Management (EIM)

Environmental innovation management (EIM) is severally examined and observed by several researchers as one of the most important existing management approaches to promote ECM programmes. Life cycle assessment may be considered an innovative way to achieve ECM. Zhu and Deshmukh (2003) propose a framework based on Bayesian decision networks, considering uncertainty for integrated analysis of the product life cycle to study the impact of design decisions on the life cycle performance. Hon and Xu (2007) address the complex relationship between the product life cycle for a family of products and the manufacturing systems performance optimization via reconfiguration as the demand pattern is ever changing, thus require innovation management to reconfigure its production capability with demand. Chung and Wee (2008) investigate the impact of the green product design, the new technology innovation and remanufacturing on the production-inventory policy to develop an inventory model with life cycle value design and remanufacturing. Branker *et al.* (2011) propose a machining microeconomic innovation model to optimize machining parameters including energy and environmental costs based on life cycle analysis (LCA) methodology.

Green or eco-design is another dimension of EIM as proposed by the researchers. A typical method is presented by Smith and Yen (2010) that uses the concepts of atomic theory to solve design modularization problems for green product design based upon three constraints; namely, material compatibility, part recyclability, and part disassemblability. Incorporating green considerations into existing modules, innovative design may be created to improve an original design. On the one hand, Xiaoyana (2012) explores the design content for 'new products' re-manufacturability and 'extended producers' responsibility', and on the other hand Sheng and Srinivasan (1995a) consider EIM through the eco-design at microplanning and macroplanning levels. While microplanning deals with the selection of processes, parameters, tooling and catalysts to generate a single geometric feature, macroplanning involves feature interactions under resource constraints, impacting significantly in energy and waste generation, including relationships between features and clustering among common setups, tooling and catalysts.

(v) Environmental Risk Governance (ERG)

Environmental risk management system is required in ECM programmes to decrease frequency of environmental accidents. Environmental risk governance (ERG) may be considered as a necessity for an ECM programme as disputes concerning industrial legacies (such as the disposal of toxic wastes) pressurize the corporations and governments. Business and governments are now taking care of environmental risks associated with economic development to meet the expectations of the society increasingly aware of environmental risks (Benn *et al.*, 2009; Cong and Freedman, 2011). Benn *et al.* (2009) identify management and governance theory addressing and developing a process-based approach by identifying five factors (namely 'sub-political' arena, key interests of the stakeholders, creating the 'community of interest and dispute' network, negotiating the deliberative strategies and implementing the decisions) to governance of environmental disputes allowing for the evolving nature of stakeholder relations in a multiple stakeholder arena. The relationship between corporate governance and pollution performance is tested by Cong and Freedman (2011) resulting into a positive relationship between good governance (i.e. early prediction of risks) and pollution performance.

3.2. Manufacturing based Operational Performance (MOP)

Manufacturing based operational performance (MOP) deals with different manufacturing related activities. Under this category, there are three methods, namely, (i) Integrated Pollution Control (IPC), (ii) Energy Consumption Control (IPC) and (iii) Lean Manufacturing Practices (LMP).

(i) Integrated Pollution Control (IPC)

Current studies suggest a need to integrate pollution control strategies like controlling emission to air with manufacturing strategy to promote ECM programmes by reducing environmental pollution (Jabbour *et al.*, 2012; Goldstein *et al.*, 2011). Goldstein *et al.* (2011) introduce a methodology for measuring and modelling manufacturers' environmental performance and the managerial and technological practices based on facility level licensing data in order to develop sector-specific indicators at various levels of aggregation. While modelling environmental performance, the indicators tend to be highly context-specific. For example, to control air pollution, the elements which constitute air pollution need to be modelled.

Sheng and Srinivasan (1995b) state that major issues for environmentally-conscious planning deal with assessment of waste streams and computational complexity of evaluating multiple processing alternatives in order to achieve overall cleaner or greener production/manufacturing system. Environmental impact of dissimilar waste streams is described using a scoring system to evaluate factors such as toxicity, carcinogenesis, irritation, flammability and reactivity. Complexity of processing alternatives is reduced by decomposing the overall environmental impact of the manufacturing system into individual features and their interactions.

(ii) Energy Consumption Control (ECC)

Researchers view energy consumption control (ECC) as a pertinent approach for ECM programmes to reduce the carbon footprints (Fang *et al.*, 2011; Dong *et al.*, 2013; Sundarakani *et al.*, 2010). Fang *et al.* (2011) develop a new mathematical programming model of the flow shop scheduling problem considering peak power load, cycle time and energy consumption associated to carbon footprint. The new model is demonstrated using a case study of a flow shop where two machines are used to produce a variety of parts. The proposed scheduling problem considers processing order of the jobs with the operation speed as an independent variable, which can be changed to affect the peak load and energy consumption. Dong *et al.* (2013) develop a linear programming model to help robust planning of energy management systems with environmental considerations. In this model, multiple uncertainties in energy activities and environmental emissions are expressed as fuzzy sets with regular and radial intervals ensuring the generation of robust solutions feasible with high probability under input data variations and reflecting the tradeoffs between the conservatism levels of solutions and probability levels of constraint violation. Results show that while decision variables rise with the increase of protection levels, higher radii fluctuation levels of radial intervals cause higher system cost with lower satisfaction degree.

(iii) Lean Manufacturing Practices (LMP)

Lean manufacturing practices (LMP) are the key elements to promote ECM programmes which may focus on the approach to minimize raw material consumption. Pongiglione and Calderini (2014) describe the approach of reducing the consumption of raw material for steel sector. This process deals without melting which allows for savings in steel mass to avoid environmental burdens. Ekins *et al.* (2014) also highlight the importance of reducing raw material consumption as a need of an ECM programme. Tsiliyannis (2014) state the necessity of minimum rate policy in order to reduce raw material consumption for environmental enhancement under growth uncertainty.

LMP also may deal with reduction of water consumption. Sachidananda and Rahimifard (2012) reveal the importance of reduction of water consumption within manufacturing applications. While Motoshita *et al.* (2011) show a damage assessment model for freshwater consumption with a case study of bottle production plant in order to minimize water footprint, Dakwala *et al.* (2014) present a systematic approach for water conservation through graphical and mathematical programming showing a case study of a float glass industry. Chew *et al.* (2013) propose optimal water consumption for pulp and paper mills based on a mixed integer non-linear programming model. Bhikha et al (2011) present an optimization method using simulation method to reduce water consumption. The validity of the simulation is tested by comparing key output variables with plant data. Jefferies *et al.* (2012) consider water footprint to assess potential impacts of products on water consumption.

Another important dimension of LMP is to reduce the wastes/solid wastes/ wastewater by recycling or controlling process through just-in-time (JIT). Yang *et al.* (2011) explore relationships between waste management practices and environmental management based on data from several manufacturing firms. The findings suggest that lean waste management is positively related to environmental management practices. Dües *et al.* (2013) provide evidence suggesting that waste control is beneficial for green practices and the implementation of green practices has a positive influence to achieve lean business practices. Hindalgo *et al.* (2013) propose a technological design based on simulation and mathematical modelling for the treatment of acidic wastewater generated by the production process of nitroaromatic compound. Mudgal *et al.* (2007) discuss the advances in treatment technologies for industrial hazardous waste management. Showing a case study, Hoveidi *et al.* (2013) propose industrial waste management with the application of rapid impact assessment matrix (RIAM) in order to assess ECM programmes.

3.3. Non-manufacturing based Operational Performance (NOP)

Non-manufacturing based operational performance (NOP) implies the activities which are not related to core manufacturing activities. Under this category, there are basically two methods, namely, (i) Green Supply Chain Management (GSCM) and (ii) Service Impact Control (SIC).

(i) Green Supply Chain Management (GSCM)

Green supply chain may be achieved by sailing the scraps/wastes/excess materials or inventory. As per Chan *et al.* (2012), this may serve as a significant driver for the practice of investment recovery. Bettayeb *et al.* (2014) develop an analytical model and planning strategy in case of excessive scrap production.

Rating of customer satisfaction on green products (such as safety, energy efficiency etc.) is another important dimension of GSCM. Huang *et al.* (2013) show environmental protection consciousness positively influences the behaviour of green consumer. While Tseng and Hung (2013) identify the gaps between customers' expectations and their perceptions in green products, Slevitch *et al.* (2013) discuss on optimization of resource allocation and green performance in the light of customer satisfaction.

However, the most important approach of GSCM is selection of the green suppliers. A model for evaluating green suppliers is proposed by Lee *et al.* (2009) with Delphi method, initially to differentiate the criteria for evaluating traditional suppliers and green suppliers followed by constructing a hierarchy to evaluate the importance of the selected criteria and the performance of the green suppliers. Buyukozkan and Cifci (2012) examine green supply chain management (GSCM) capability dimensions to propose an evaluation framework for green suppliers. The nature of supplier selection is a complex multi-criteria problem including both quantitative and qualitative factors which may be conflicting and uncertain in nature. To solve this problem, they use a hybrid fuzzy multiple criteria decision making (MCDM) model that combines the fuzzy Decision Making Trial and Evaluation Laboratory Model (DEMATEL), the Analytical Network Process (ANP), and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). To move beyond traditional supplier selection approach, Yeh and Chaung (2011) introduce green criteria into the framework of supplier selection criteria to develop an optimum mathematical planning model for green partner selection, involving four objectives like cost, time, product quality and green appraisal score. For solving these conflicting objectives, they adopt two multi-objective genetic algorithms to find the set of Pareto-optimal solutions, utilizing the weighted sum approach so that more number of solutions can be generated.

(ii) Service Impact Control (SIC)

Service impact control essentially deals with the adoption of green transportation by using fuel efficient or environment friendly transportation system. Lin *et al.* (2014) propose a genetic algorithm based optimization model for supporting green transportation operations. A cost generation engine is designed to perform a comprehensive cost comparison and analysis based on a set of economic and environmental cost factors in order to suggest optimal transportation schemes. To evaluate the success of an ECM programme in the light of SIC through green transportation, Satunin and Babkin (2014) present a multi-agent intelligent system to provide flexibility in transportation. While Song *et al.* (2013) propose a simulation based optimization in a heuristic way to propose to minimize transportation cost, Bjorklund (2014) discuss the drivers and hinders of purchasing green transportation services.

Adoption of green packaging (use of environment friendly materials, reuse/ reverse logistics practice, consideration of less weight) is another important dimension of SIC as has been mentioned by different researchers. Ferrão *et al.* (2014) and Cruz *et al.* (2012) show the benefit of green packaging in terms of cost savings presenting case studies of Portugal. González-Buesa *et al.* (2014) show the need of bio-based packaging materials to ensure quality and safety during service. Reducing the weight of packaging materials is also considered by the researchers and practitioners (Saghir, 2004; Report of IBEF, 2014). Ramos *et al.* (2014) propose a multi-objective reverse logistics system based on Pareto front to balance costs with environmental and social concerns.

Societal concern for protection of natural environment such as green disposal and plantation of trees are highlighted by the researchers to control the impact on environment. Alena and Libor (2012) consider green disposal in their conceptual research model to assess the environmental impact of a manufacturing organization. Rehman *et al.* (2013) consider a green manufacturing framework including green disposal initiatives and validate the framework using an Indian steel industry. Okimori *et al.* (2003) and Overbeek *et al.* (2012) discuss the importance of tree plantation as a societal concern. Karumbidza (2005) conducts a study of the social and economic impacts of industrial tree plantation in South Africa which is an essential part of an ECM programme.

4. CRITICAL APPRAISAL OF THE EXISTING METHODS

In this section, existing methods and indicators for ECM programmes as addressed by different researchers are critically appraised with their characteristic features (see **Table 1),** merits and limitations (see **Table 2)**. Basically ECM programmes consider pollution control methods at different stages of production, waste minimization, and proper or optimal utilization of resources. Governments, global organizations and communities need to collaborate and develop feasible, acceptable and effective strategies to safeguard natural resources. Most of the research works to evaluate ECM programmes have emphasized only on large scale manufacturing organizations, but not small and medium scale manufacturers. It is not clearly explained by majority of the researchers whether the proposed tools, techniques and methods would be fruitful for the small and medium scale enterprises (SME). Hence, in case of limited financial resources, how the SMEs can evaluate the ECM programmes that should be the matter of consideration for the researchers and practitioners in this particular area, because SMEs collectively contribute significantly to environmental pollution.

One important characteristic to evaluate ECM programmes which may be noticed is the application of different statistical modelling as highlighted by several researchers. Based on the relationships among different indicators in the form of mathematical equations, the statistical models are formalized. While linear programming is used to optimize a linear objective function subject to linear equality and linear inequality constraints, nonlinear programming is used to optimize a non-linear objective function or where some of the constraints are nonlinear over a set of unknown real variables or indicators. In some cases of GSCM, multiple-criteria decision making (MCDM) techniques are applied considering several criteria in decision making environments. However, in case of other methods the application of MCDM is not considered by the majority of the researchers. Different tools and techniques of Industrial Engineering (e.g. Ishikawa's Fishbone Diagram or Cause-and-Effect Diagram, Pareto Analysis etc.) are used to identify the potential causes of environmental pollution. In many cases, different hybrid or integrated methods are applied by the researchers to evaluate the ECM programmes. However, majority of the integrated methods do not include several dimensions of environmental consciousness.

Researchers have basically focused on a single dimension or a few dimensions. Analyses are carried out based on the sectors or particular case. There is no holistic framework addressed by the researchers which may be applied for any manufacturing organization irrespective of its size (i.e. small, medium or large) in order to evaluate ECM programmes. Therefore, a comprehensive and integrated holistic generic framework applicable for any manufacturing organization may be considered to be a prime necessity in order to evaluate different ECM programmes. This holistic framework should address multiple dimensions of environmental consciousness.

Most of the researchers have considered environmental pollution in terms of air pollution and water pollution. In a number of cases, air pollution controlling approach is coupled with energy consumption reduction policy. Particularly, in case of energy intensive industries energy consumption reduction techniques may act to cut down the level of air pollution. However, there is no generic approach to

Table 1
Methods and Indicators for ECM programmes

Methods	*Indicators*	*Sources*
Issue: Environmental Proactivity (EP)		
(i) Strategic Environmental Assessment (SEA)	Top management support/commitment and manpower involvement including environmental training	Toke *et al.*, 2012; Sambasivan *et al.*, 2013; Jabbour *et al.*, 2013
	Approach to increase environmental expenditure (operational cost, training cost, environment friendly materials cost, waste and water treatment/recycling cost)	Sueyoshi and Goto, 2009; Jaraite *et al.*, 2012; Wang *et al.*, 2014
	Approach to maintain regulations imposed by the government and stakeholders	Choi *et al.*, 1997; Eiadat *et al.*, 2008
	Approach to have ISO 14001 certification or environmental policy or formal environmental management system (EMS) for green manufacturing (GM) and green supply chain management (GSCM)	Sarkis, 1995; Toke *et al.*, 2012; Jabbour *et al.*, 2013
	Approach to have total quality management system/ISO 9001 certification	Terziovski et al, 2003; Casadesús *et al.*, 2008; Zhu *et al.*, 2013
(ii) Sustainability Measurement (SM)	Long term sustainable initiative regarding GM and GSCM over budget schedule	Toke *et al.*, 2012; Sambasivan *et al.*, 2013; Joung *et al.*, 2012
	Recycling initiatives like joining local recycling organization or establishing collaboration with same sector industry	Ricoh Group Sustainability Report, 2007, Despeisse *et al.*, 2012
(iii) Intelligent Environmental Management (IEM)	Computer/software based environmental management or communication management to exchange green initiatives among similar sectors	Burke and Gaughran, 2006; Butler, 2011; Dao *et al.*, 2011; Giovannini *et al.*, 2012; Kuo *et al.*, 2012
(iv) Environmental Innovation Management (EIM)	Life cycle assessment with environmental database of products	Zhu and Deshmukh, 2003; Hon and Xu, 2007; Chung and Wee, 2008; Branker *et al.*, 2011
	Approach of green or eco-design (with cross-functional integration, if required)	Sheng and Srinivasan, 1995a; Smith and Yen, 2010; Xioyana, 2012
(v) Environmental Risk Governance (ERG)	Environmental risk management system to decrease frequency of environmental accidents	Benn *et al.*, 2009; Cong and Freedman, 2011

Issue: Manufacturing based Operational Performance (MOP)		
(i) Integrated Pollution Control (ICP)	Reduction of emission to air	Goldstein *et al.*, 2011; Jabbour *et al.*, 2013
	Achieved overall cleaner or greener production/ manufacturing system (such as proper coolant use, chip handling system, reduction of toxic/ toxic/hazardous/harmful materials etc.)	Sheng and Srinivasan, 1995b
(ii) Energy Consumption Control (ECC)	Reduction of energy consumption and carbon footprint	Fang *et al.*, 2011; Dong *et al.*, 2013; Sundarakani *et al.*, 2010
(iii) Lean Manufacturing Practices (LMP)	Reduction of raw material consumption	Ekins *et al.*, 2014; Pongiglione and Calderini, 2014; Tsiliyannis, 2014
	Reduction of water consumption	Bhika *et al.*, 2011; Motoshita *et al.*, 2011, Jefferies *et al.*, 2012; Sachidananda and Rahimifard, 2012; Chew *et al.*, 2013; Dalewala *et al.*, 2014
	Reduction of wastes/solid wastes/wastewater by recycling or controlling process through lean manufacturing/just-in-time (JIT)	Mudgal *et al.*, 2007; Yang *et al.*, 2011; Dües *et al.*, 2013, Hidalgo et al, 2013; Hoveidi et al, 2013

Issue: Non-Manufacturing based Operational Performance (NOP)		
(i) Green Supply Chain Management (GSCM)	Sale of scraps/wastes or excess materials or excess inventory	Chan *et al.*, 2012; Bettayeb *et al.*, 2014
	Rating of customer satisfaction on green products (such as safety, energy efficiency etc.)	Slevitch *et al.*, 2013; Tseng *et al.*, 2013; Huang *et al.*, 2014
	Approach of environmental auditing of suppliers with questionnaire to select green suppliers, mentioning environmental requirements like product testing report, bill of material, ISO 14001 certification in order to achieve green purchasing	Lee *et al.*, 2009; Yeh and Chaung, 2011; Buyukozkan and Cifci, 2012
(ii) Service Impact Control (SIC)	Adoption of green transportation by using fuel efficient/environment friendly transportation system	Bjorklund et al, 2011; Song *et al.*, 2013; Lin *et al.*, 2014; Satunin and Babkin, 2014
	Adoption of green packaging (use of environment friendly materials, reuse/reverse logistics practice, consideration of less weight etc.)	Saghir, 2004; Cruz *et al.*, 2012; Buesa *et al.*, 2014; Ferrão *et al.*, 2014; González-Buesa *et al.*, 2014; Ramos *et al.*, 2014; Report of IBEF, 2014
	Societal concern for protection of natural environment such as green disposal, plantation of trees etc.	Okimori *et al.*, 2003; Karumbidza, 2006; Alena and Libor, 2012; Overbeek *et al.*, 2012; Rehman *et al.*, 2013

model and forecast the elements of air pollution reducing the variability. Regarding water pollution, stochastic modelling is considered in many cases to account trend and seasonality. Proper utilization of the resources with improved waste management may benefit a manufacturing organization greatly by minimizing production cost. Which particular area(s) should be focused to measure and evaluate environmental performance is highly context specific and may be expressed by identifying the root causes behind the inefficient ECM programmes for a particular manufacturing organization or sector.

Nowadays, environmental consciousness is not only necessary to protect the environment, but also it is a way for the manufacturing organizations to make money as has been revealed by majority of the researchers. However, some of the researchers have argued that environmental proactivity is not always positively correlated with financial performance. Hence, before dealing with the indicators to evaluate the ECM programmes, the relationship between environmental proactivity and financial performance needs to be checked for a given scenario. If the relationship is found to be positive, it should be revealed how the environmental proactivity is positively related to financial performance (i.e. through manufacturing-based activities or through non-manufacturing based activities) in order to identify which particular indicators may be considered to evaluate the ECM programmes based on input and output analysis.

5. GENERIC FRAMEWORK TO EVALUATE ECM PROGRAMMES

As any manufacturing process may have some unique characteristics, it may be difficult for the researchers and practitioners to select a suitable generic research framework to evaluate ECM programmes and suggest possible solutions. In this section, based on the understanding of available literature a comprehensive, integrated and holistic generic framework applicable for any manufacturing organization is proposed in order to evaluate ECM programmes. The steps involved in the framework are explained below. The proposed framework has four specific phases, viz. (i) Pilot survey and data collection phase, (ii) Data analysis phase, (iii) Core modelling phase, and (iv) Performance analysis phase. The details of these phases and the steps involved are described in this section. The framework in terms of phases and steps involved, and sources of data, required tools and techniques is described with a flow chart (see **Fig. 1**).

(i) Pilot Survey and Data Collection Phase

This phase consists of the two steps viz. (a) pilot survey and (b) evaluation-related detailed data collection.

(a) Pilot Survey: This part involves determining the relationship between environmental proactivity (EP) and financial performance (FP) for a given

Table 2
Merits and Limitations of the Methods for ECM programmes

Merits	*Limitations*
Issue: Environmental Proactivity (EP)	
1. Strategic Environmental Assessment (SEA) provides an opportunity for the public to comment or express views on a strategic action before it is formally agreed.	1. Experiments or tests for Strategic Environmental Assessment (SEA) may be expensive. SEA has to deal with uncertainties from a local up to global level throughout the course of the strategic action.
SEA also promotes better consideration of alternatives incorporating environmental and sustainability considerations in strategic decision-making.	Baseline data for SEA may not be available. Public participation may not yet be in place to adequately carry out EIA. Moreover it takes time and resources.
2. Environmental Sustainability Measurement (ESM) helps to determine the long-term impact of the manufacturing processes and products on the environment for a particular manufacturing organization.	2. Environmental Sustainability Measurement (ESM) has the problem or disadvantage to incorporate changes and uncertainties with respect to time.
3. Intelligent Environmental Management (IEM) can store important environmental data and can retrieve as per requirement.	3. Intelligent Environmental Management (IEM) may not be suitable for SMEs as it may require costly software.
4. Environmental Innovation Management (EIM) helps to develop innovative ideas regarding planning or decision making in a manufacturing system to improve the environmental performance.	4. Environmental Innovation Management (EIM) requires proper training among the employees. Training may be expensive and may not be liked by all the employees or workers.
Life Cycle Assessment (LCA), being a part of EIM, quantifies the emissions into air, water and land that take place in every life cycle phase detecting significant changes in the environmental effects between the life cycle phases. LCA estimates the effects of materials consumption and environmental emissions on human and the eco-system comparing the consequences to human and to the eco-system of two or more competitive products or processes.	Though Life Cycle Assessment (LCA) has the potential to structure a flow of quantitative information between different stakeholders (industry, customers, researchers, governmental agents, local communities and other groups) and may be used internally within an industry for process improvement, technology selection and reporting, and externally to support marketing and to inform different stakeholder groups; the accuracy of an LCA study depends on the quality and the availability of the relevant data, and hence if these data are not accurate enough, the accuracy of the study is limited.

contd. table

Merits	*Limitations*
5. Environmental Risk Governance (ERG) ascertains the significance or acceptability of the risks and the need for management action in order to prevent or minimize the risks. ERG not only improves overall risk management, but also gains competitive advantage by identifying new environmental business opportunities and adding value to clients.	5. Environmental Risk Governance (ERG) may not coincide with the social scale, or level of the policy intervention. ERG has a tendency to focus more on the threats rather than the opportunities. ERG also focuses more on technology risk rather than the organizational features of the problem.
Issue: Manufacturing based Operational Performance (MOP)	
1. Integrated Pollution Control (IPC) has the advantage of taking into account the effects of activities and substances on the environment as a whole, when assessing the risks they pose and when developing and implementing controls to limit their release.	1. Integrated Pollution Control (IPC) has the disadvantage of taking into account the reverse activities where some particular activities may improve at the cost or deterioration of some other activities.
2. Energy Consumption Control (ECC) is an approach which can be adopted by both large scale industries and SMEs as well.	2. Many methods of Energy Consumption Control (ECC) deals with complex techniques requiring enough mathematical knowledge for the managers.
3. Lean Manufacturing Practice (LMP) helps to reduce the wastes which may lead to reduce the production cost. LMP helps to reduce cycle time and work-in-process inventory. Increased capital equipment utilization is another benefit to employ LMP. It helps to eliminate problems with improved visual management. LMP may lead to continuous improvement with reduced manpower.	3. Lean Manufacturing Practice (LMP) may not be suitable for low-volume manufacturers as the cost of implementation of lean manufacturing system is usually high. Very often lean manufacturing system is not found suitable in the process industries as there is no concept of unit manufacturing.

Issue: Non-Manufacturing based Operational Performance (NOP)	
1. Green Supply Chain Management (GSCM) leads to increase green competition which is very important for green manufacturing. GSCM helps to identify the best possible suppliers in order to generate revenue and sustain continuous profitability with improved overall business efficiency.	1. Green Supply Chain Management (GSCM) may not be very fruitful method for the SMEs because green products or raw materials may cost more. Uncertainty of the elements of GSCM is a major problem to employ GSCM. Another problem area is suppliers' reluctance to change towards GSCM.
2. The main advantage of Service Impact Control (SIC) is to reduce the environmental impact in the downstream activities, basically of the production line and to control the pollution level through plantation in order to benefit the locality and society.	2. To control the service impact proper planning is required. Green transportation system initially may cost more. If battery driven vehicle is used as a mode of green transportation, charging the battery is a problematic area that requires long time consumption.
Green packaging may eliminate unnecessary packaging layers. It may shrink the packages to the most optimal size and weight possible for given contents. Use of green materials may lead to recycling and reuse. Green packaging system may consider the use of renewable resources which are biodegradable and compostable materials.	Recycled material used for packaging has a limited reuse because of the strength factors, particularly if it is postconsumer recycle. Biodegradable materials like virgin wood fiber may require a huge amount of bamboo trees depleting the bamboo forests. Another disadvantage of using biodegradable packaging is that it may soon get spoiled for decomposition causing harm to the product.
Green disposals can control environmental pollution, particularly water and land pollution by saving the microorganisms of water and soil, leading to maintain the biodiversity of nature. Green disposal may reduce the exposure of people to biohazards. It may also lead to reprocess or reuse of the wastes.	The major disadvantage of green disposal is that proper preservation technique or method is required to stock the wastes. It requires preservation cost and also consumes space for dumping. Without proper preservation wastes may pollute the environment and may be considered as health hazards.

scenario. This relationship may be identified through a questionnaire survey distributed among the manufacturing organizations of a particular region. Different regions may be selected to compare the results. Structural Equation Modelling (SEM) (includes reliability analysis in terms of Cronbach's alpha) may be used to determine the relationship. Required indicators (termed as environmentally conscious manufacturing indicators or ECMI) to be applied (based on a five point scale) in SEM may be selected from literature review as described in the previous section. If the relationship is found to be positive, it is to be determined how they are positively correlated (i.e. through MOP or NOP) in order to identify the relevant indicators required to assess the ECM programmes. SEM may be applied by using SPSS (Statistical Package for the Social Sciences) or AMOS (Analysis of Moment Structures) or LISREL (Linear Structural Relations).

(b) Evaluation-related Detailed Data Collection: This part involves collection of relevant ordinal and continuous data of the indicators to evaluate ECM programmes. Ordinal data may be represented by a 0-4 point (0, 1, 2, 3 and 4 for no influence, low influence, moderate influence and high influence, very high influence respectively) scale and 1-9 point (1, 2, 3, 4, 5, 6, 7, 8 and 9 for equal importance weak or slight importance, moderate importance, moderate plus importance, strong importance, strong plus importance, very strong or demonstrated importance, very very strong importance and extreme importance respectively) scale.

(ii) Data Analysis Phase

The main objective of data analysis phase is to identify inefficient ECM programmes. This phase consists of three steps, namely (a) DEMATEL (Decision Making Trial and Evaluation Laboratory) Analysis, (b) ANP (Analytic Network Process) and (c) Restricted multiplier based DEA (Data Envelopment Analysis) Model.

(a) DEMATEL Analysis: Though a particular manufacturing process is specific in nature, however it might be controversial in some cases to what extent an indicator affects other indicators or is influenced by other indicators. Hence, in this step, the interdependence relationship among the ECMIs identified in the pilot survey may be established based on the responses (0-4 point scale as mentioned in the previous phase for pairwise comparison) given by the experts (e.g. environmental/production managers) of a particular manufacturing organization. Establishment of this relationship is required to enable the next step of this phase (i.e. ANP). Microsoft Excel may be used as software for calculation purpose.

(b) ANP: To determine the weightage or range of weightage of the indicators ANP may be used which represents complex interrelationship among the alternatives considering a dynamic decision environment. For pairwise comparison, experts' opinion may be categorized based on a 1-9 point scale as mentioned in the previous phase. In order to realize whether the judgments of the decision makers follow logic or just putting some random numbers, value of consistency ratio needs to be checked which must be less than 0.1. Finally in this method, a column stochastic supermatrix is formed to reflect the global priority vectors for each of the decision makers. Thus, a range is created for each of the ECMIs enabling the next step of this phase (i.e. restricted multiplier DEA model). Super Decision software may be used for ANP.

(c) Restricted-multiplier DEA Model: This method may be applied to calculate the efficiency of each ECM programme in order to identify the inefficient ECM programmes. The advantage of using this method is that it considers multiple inputs and outputs simultaneously to determine the efficiency of each decision making unit (DMU) so that managerial preferences may be included by setting upper and lower bounds for each input and output weight (often termed as assurance region or AR). Hence, this step determines the critical ECMIs (CECMI) based on slack. DEA frontier software (add-in of MS Excel) may serve this particular step.

(iii) Core Modelling Phase

This phase consists of two steps, namely (a) Selection of modelling techniques for CECMIs, and (b) Model building for CECMI.

(a) Selection of modelling techniques for CECMIs: What kind of modelling technique is required that is selected in this step based on the seasonality, trend and noise of the CECMIs after plotting the time series data. In this step, the seasonality is removed to make the data suitable for model building. Minitab or Statgraphics software may be used for this step.

(b) Model building for CECMI: In this step, different seasonally adjusted CECMIs are compared to identify the best model. For this purpose automated regressive integrated moving average (ARIMA) may be applied as it is one of the most important tools for time series analysis which is used for stochastic modelling to reflect the actual or practical scenario in a better way compared to the deterministic processes. Hence, ARIMA may be used to model and forecast the CECMIs. Minitab or Statgraphics software also may be used for this step.

(iv) Performance Analysis Phase

After formulating the models, the next step is to analyze the environmental performance of the environmental bottleneck manufacturing operation based on CECMIs. This may be done through four steps, viz. (a) Identification of the environmental bottleneck manufacturing operation, (b) Variability analysis of the CECMIs, (c) Verification of CECMIs through CTQs (Critical to Quality) and (d) Minimizing the variability for environmental bottleneck.

(a) Identification of the environmental bottleneck manufacturing operation: The first step of this phase is to identify the environmental bottleneck manufacturing operation through Ishikawa's Fishbone Diagram or Cause-and-Effect Diagram. This diagram may be obtained after reviewing the literature and discussing with the experts (e.g. environmental/production managers) in a brainstorming session for a particular manufacturing sector/organization. Though the categories of Cause-and-Effect Diagram typically include people, methods, machines, materials, measurements and environment, for the current step only environmental elements should be considered to identify environmental bottleneck that indicates a particular manufacturing operation where excessive pollution is occurred compared to the other manufacturing operations of the entire manufacturing process. Even if the environmental performances of the other manufacturing operations are improved, the overall environmental performance of the entire manufacturing process may not be improved significantly unless the environmental bottleneck manufacturing operation is improved.

(b) Variability analysis of the CECMIs: This is the second step of the performance analysis phase where variability of the elements of CECMIs for environmental bottleneck manufacturing operation is noticed meticulously. In this particular step, the upper control limit (UCL) and lower control limit (LCL) of the elements of the CECMIs are determined due to the process variability. If the variability of that particular element is high along with frequently crossing the specified or permissible limits (as set by the company or government), variability of those elements should be reduced. Variability analysis may be performed using Minitab or Statgraphics software.

(c) Verification of CECMIs through CTQs (Critical to Quality): This is the third step of the performance analysis phase where the CECMIs are verified through CTQs. CTQs are defined as the internal critical quality parameters that relates to the wants and needs of the customers. Among several functional characteristics, major or important functional characteristics are identified through Quality Function Deployment (QFD) matrix. Only the important functional characteristics are critical to quality. Hence, CECMIs may be treated as equivalent to CTQs and verified through the QFD matrix in order to proceed further for performance analysis purpose. In recent times, various environmental indicators, air pollution indicators in particular, are critically analyzed using QFD matrix.

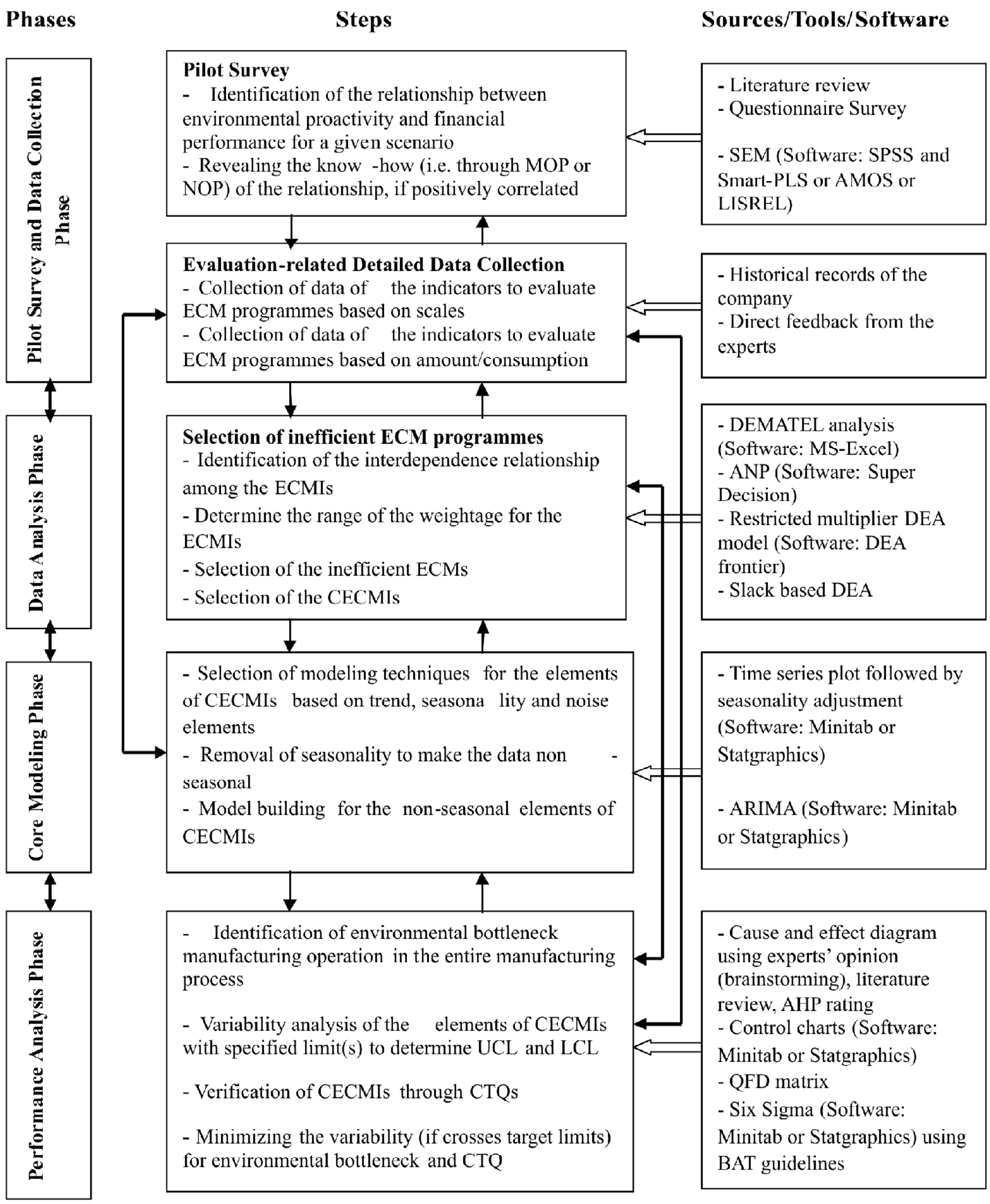

Figure 1: A Generic Framework to Evaluate Environmentally Conscious Manufacturing (ECM) Programmes

(d) Minimizing the variability for environmental bottleneck: This is the final step where the variability of the elements of CMCMIs may be reduced applying DMAIC or DMADV (Define-Measure-Analyze-Improve/Design-Control/Verify) principle of Six Sigma which has been quite successful in the area of environmental problem solving. Artificial Neural

Network (ANN) may be used as a tool of Six Sigma if non-linear relationship exists between the output (i.e. an element of CECMI) and most of the inputs (i.e. input process parameters to forecast the element of CECMI). Root causes of variation may be eliminated or improved using BAT (Best Available Technologies) guidelines which should be maintained to sustain the improved process capability. Minitab or Statgraphics software may be used for Six Sigma.

It is also necessary to understand the inherent characteristic features/selection norms of the analysis/modelling techniques used in the above mentioned generic framework. Some of the important characteristic features/selection norms of the techniques are shown in **Table 3**.

Table 3
Inherent Characteristic Features/Selection Norms of Analysis/Modelling Techniques

Analysis/Modelling Technique	*Inherent Characteristic Features/Selection Norms*
Structural Equation Modelling (SEM)	(i) Considers general linear model to evaluate how well the hypothesized structure fits the data using maximum likelihood. (ii) In SEM, the reliability analysis is performed in terms of Cronbach's alpha; importance to be given only those indicators having value equal or greater than 0.7.
Decision-Making Trail and Evaluation Laboratory (DEMATEL)	(i) May confirm the interdependence of the indicators to reflect the characteristics or relationships within a system.(ii) A group of experts is used to judge the degree of direct influence based on pairwise comparison.
Analytic Network Process (ANP)	(i) Considers a dynamic decision environment. (ii) Represents complex interrelationship among the alternatives.
Data Envelopment Analysis (DEA)	(i) Multiplier-based DEA model sets weightage restrictions to the indicators in a multi-factor productivity approach. (ii) Helps to determine inefficient decision making units. (iii) Slacks identify the root causes of the inefficient units based on the target level.
Autoregressive Integrated Moving Average (ARIMA)	(i) Group of orderly time series data formed over time is described by a corresponding mathematical model. (ii) Future data are predicted according to the model and previous values and present values of the time series data.

contd. table 3

Analysis/Modelling Technique	*Inherent Characteristic Features/Selection Norms*
Cause and Effect Analysis	(i) Achieved by Ishikawa's Fishbone Diagram that categorizes and identifies root causes. (ii) Each cause for imperfection is considered as a source of variation.
Control Charts	(i) Tool to determine whether a process is in a state of statistical control. (ii) Stable process outside specification limits needs to be improved through a deliberate effort to understand the causes of current performance.
Six Sigma	(i) Implies less than 3.4 defects per million opportunities (or a success rate of 99.9997%). (ii) Structured method of problem solving applying DMAIC or DMADV (Define-Measure-Analyze-Improve/Design-Control/Verify) principle widely.
Artificial Neural Network (ANN)	(i) Soft computing method to improve the process knowing the importance of the input process parameters in advance to influence the output. (ii) Follows data-driven trained methodology. (iii) Normally uses a feed-forward architecture to describe three different types of layers (input, hidden and output) similar to the brain of the humans. (iv) All the layers comprise certain number of processing nodes termed as neurons.

6. CONCLUSIONS

In this paper, an attempt has been made to understand the complexities of the ECM programmes, the challenges and their sources, and the advances made so far to address the ECM programmes. Based on literature review, existing methods and indicators are described to assess ECM programmes. The indicators are classified according to the existing methods followed by identifying the research gap. Thereafter, to bridge the research gap, a comprehensive, integrated and holistic generic research framework is proposed to evaluate the ECM programmes. This framework will help the manufacturing industries to measure their environmental consciousness properly in order to improve the process and productivity with better environmental management practices. Hence, this research framework has direct managerial implications. Overall, this research framework gives a comprehensive view to assess the ECM programmes. This research work also may be helpful for professionals dedicated to teaching environmental management and operations management.

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