
Syed Ibrahim Dilawer*, Dr. J. Eduardo Munive-Hernandez**, M.A. Raheem junaidi***
* Department of Advance Manufacturing Engineering, University of Bradford, Bradford, U.K
** Department of Advance Manufacturing Engineering, University of Bradford, Bradford, U.K
*** Department of Mechanical Engineering, Osmania University, Hyderabad, INDIA

ABSTRACT
Energy efficiency is one of the significant drivers for sustainability and its importance has grown within manufacturing environments. It is now considered among one of the decision making factors such as cost, productivity and flexibility. Though, in most of the cases the energy intake of the various components of the manufacturing systems like machine tools, are considered using average to very high energy consumption models in the manufacturing sector. This Research paper presents an overview of the various energy efficiency approaches, concentrating in both the production and the machine tool level and further discussing how these two can be integrated together. In addition, the main challenges that arise towards the energy efficient manufacturing in the present day are discussed identifying the main barriers from both the technology and the cultural point of view. This research paper also developed three different sets of green performance measurement indicators. The first are with respect to strategic, tactical and operational aspects in the enterprise, the second set of indicators are developed through the three aspects of sustainability namely environmental, social and economic aspects. The third set of green performance indicators were developed by considering the whole reverse supply chain concept in the enterprise. Also the importance and implementation of these indicators in the performance measurement system was discussed. Even though there have been studies on the implementation of green performance measurement system indicators in the enterprise for improved environmental performance, yet there has not been a comprehensive study in the performance measures with different perspective for their implementation. This research paper aims in filling that gap in an attempt to discuss the need for energy efficiency in manufacturing and the development of green performance measurement indicators with its implementation in the enterprise to increase not only the environmental efficiency but also its competitiveness among manufacturers.

Keywords - Sustainability, Production, Energy, Manufacturing, Performance Measurement

I. INTRODUCTION
Manufacturing is one of the foremost wealth generating activities. It can be defined as the transformation of information and materials into goods for the satisfaction of human needs. However, turning the raw materials into consumer products is also a key source of environmental pollution. This environmental pollution can be the direct result of the manufacturing process, or indirectly through the usage of energy for running these processes. Waste in manufacturing involves a very diverse group of materials, and depends on the technology used, the nature of the raw material processed and the quantity that is discarded at the end of the chain. The large use of energy for industrial operations in Europe (31% of the whole consumed energy) is responsible for significant CO₂ emissions and thus climate change [10] [5]. Over the years, the demand for goods, energy and natural resources has been increasing, thus we have use more energy efficient production methods. For making this reality, the manufacturing sector has to maximize their gains from minimum resources.

The affordability and the availability of the energy resources is becoming a major parameter in affecting the entire cycle of the production phase. Manufacturing sector is responsible for more than 30% of the total energy consumption of the entire world [3] [11] [39], and utilizing some of the latest technologies and industrial best practices have the potential for reduction of CO₂ and Energy consumption. By adapting such approached on a global scale could save up to 25 to 35 EJ of energy every year, which equals to around 18 to 20% of the current energy use in the industry [11].

Though, the production systems performance is assessed by monitoring the manufacturing attributes which are time, quality, cost and flexibility as shown in Fig.2. The manufacturing efficiency has always been focused on the technological advances and improvements, but these advances are often at the
expense of an increased energy consumption and intern effect the CO₂ emissions. These four manufacturing attributes do not take into account the energy or the resource efficiency which are very important for sustainability.

Sustainability is a very important attribute which has to be taken into account when making manufacturing decisions. It is very evident that the manufacturing processes are not having an optimized energy consumption which results in excessive energy and resources usage. Thus we have to include sustainability in the manufacturing decisions, as shown in the Fig.1 and Fig.2 [4] [32].

![Fig.1 The three aspects of Sustainability](image)

![Fig.2 Sustainable Decision making attributes in manufacturing](image)

The Key performance Indicators (KPIs) in the manufacturing sector are well defined for its attributes, such as for ‘cost’ as a manufacturing attribute have a number for factors or KPI’s like facility cost, equipment cost, material cost, labor cost etc. Similarly the manufacturing attribute ‘quality’ also has many KPI’s such as measurements, roughness of the surface etc, on the other hand ‘time’ is monitored utilizing KPI’s like cycle time, lead time etc. Energy efficiency in the light of sustainability is the procedures that reduce the volume of the energy per unit of the industrial production. It is also defined as the goal to reduce the energy which is required to produce products and services while achieving the same quality with minimum energy input [7] [9] [33]. A large number of Key performance indicators for energy consumption have been identified like consumption of energy per product, total energy used etc which can be categorized into many distinctive categories as energy consumed (energy per product), financial performance (energy cost), environmental performance (greenhouse gases emissions) etc. The main aim of this research paper is to present an alternate method for the problems in energy efficiency that could address the machine tools and manufacturing energy consumption. Furthermore the problems towards the energy efficient manufacturing and its remedies are identified and discussed. This paper also develops green performance measurement indicators for the enterprise environmental improvement.

Area of Research: Energy efficiency is analyzed in five different stages mainly process stage, cell or multi machine stage, facility, multiple factory stage and the global supply chain stage. Each and every stage has different assumptions, different inputs and gives different outcomes. This research paper is focused on two very generic levels, the manufacturing system level and the machine tool level. This research paper also developed three different sets of green performance measurement indicators. The first are with respect to strategic, tactical and operational aspects in the enterprise, the second set of indicators are developed through the three aspects of sustainability namely environmental, social and economic aspects. The third set of green performance indicators were developed by considering the whole reverse supply chain concept in the enterprise. Also the importance and implementation of these indicators in the performance measurement system was discussed with future scope for improvements.

II. THE ENERGY EFFICIENCY IN MACHINE TOOLS

In the recent studies, it is clear that the consumed energy from machine tools while machining is greater than the theoretical energy which is required to the formation of chip [14] [17]. It is also shown that the cutting energy in machine tool is just 15% of the total amount of energy which is consumed by an automatic machine tool during machining as shown in Fig.3 (a).

![Fig.3 (a) Average Percentage of energy used in a machine tool during machining process](image)

The results were same for the case for grinding process as well hence it is very essential that steps are required to measure the consumption of energy accurately during the process. For the purpose of measuring the energy consumption of the machine tool it is required to thoroughly design the monitoring system. Thus we have to monitor each and every
system and sub systems individually; as we can see in Fig.3 for the grinding operation all the systems and subsystems are monitored. During the monitoring operations, the consumption of energy due to the process variable also has to be considered, as we can see through the Fig.3 that for the grinding operation all the energy demand is depicted. Hence the total amount of energy which is required by a machine tool could be determined through the equation

\[ E_{\text{Total}} = E + E_{\text{Peripherals}} \]

Where \( E \) is the amount of the energy which is required for the physical process to occur, \( E_{\text{Peripherals}} \) is the amount of energy which is consumed from the machine tool like for the operation of coolant pump etc.

\[ E_{\text{Peripherals}} = E_{\text{Background}} + E_{\text{Load}} \]

The background energy (E Background) usually depends on the tools used on the machine and for the case of grinding, these generally comprises of the energy used by the coolant pump, the various electronics and the control unit etc. The load energy (E Load) usually depends on the specific process, in our case of grinding it mostly comprises of the specification of the work piece which includes the material, size, weight of the work piece, the parameters selected for the process etc. This type of analyzing could be carried out for all the conventional manufacturing processes and the non-conventional manufacturing processes [3] [22] [33].

A similar property of most of the manufacturing processes either it be a conventional one or non-conventional one, in both cases the machine consumes almost more than 50% of the total energy even when it is idle. Thus it is clear that lot of energy is wasted and which also brings the need for improvement in the design of the machine tool, like the sharing of the same peripherals in between machine tools in the basic manufacturing system.

The energy reductions could also be caused through the better optimization of the machining process like the reduction of steps in the manufacturing process, by the efficient planning of operations, and by optimizing the tool path [5] [17] [39].

### III. ENERGY EFFICIENCY IN MANUFACTURING

Energy efficiency can be achieved in every stage of the manufacturing process [7] [11]. The lean, Six Sigma and Kaizen philosophies [36] have given many significant benefits to the manufacturing processes and system by the concentration and the focus towards the flow processes and the waste removal in the manufacturing.

The lean principles have helped in improving the flow of material and improving the customer delivery. Many of the latest developed lean tools have helped in the process of energy saving in manufacturing [18]. These processes might be applied to get economical improvements but it also helps in the environmental improvements as well.

The Lean principle focuses on the addition of the value adding operations and the removal of waste in non-vale adding operations. This methodology, if applied in the manufacturing operations will help in improving the energy efficiency.

In the manufacturing system level, energy savings can be achieved from very simple prevention activities which might include switching off the energy consumables like production equipment when they are not in use. More savings can be achieved from managing equipment effectively and efficiently when they are used like batching in manufacturing for higher energy efficiency etc.

Waste hierarchy in manufacturing is one of the ways by which we could energy efficiency actions could be prioritized and classified. Waste hierarchy has been discussed extensively by many authors like Toyota [26] explained about the six energy reduction attributes among them four attributes namely eliminate, repair, stop and reduce were said to be very effective and important [3] [32] [39], among them few have explained in depth all the elements of the waste hierarchy, similarly the energy hierarchy could be comprises of Prevention, Reduce, Reuse and Disposal.

In a manufacturing system energy prevention may include turning the power down to those equipment’s and other machinery when not in use and after the shift, switching off the clean air handling systems when not in use etc [3] [25] [32]. The energy reduction aspect in a manufacturing environment may include improving and refining the cellular and batch manufacturing or products keeping in mind the
tion of disposed energy from one process to use it for another process etc, while dispose may include use of environment as a heat sink rather than to use power to cool.

IV. ENERGY SAVING MANAGEMENT

To waste material hierarchy is very clearly established and explained in the research[3][32][39] which is generally represented by a hierarchy with prevention being the first preferable action which could be taken followed by reduction, reuse, recycle, recover and lastly disposal. Here prevention has been given priority over others whereas disposal has the least favored option when compared to other mentioned applications.

The following actions or tactics should be considered for moving from just sustainable concepts to the sustainable manufacturing operations. These concepts include Prevention, waste reduction, resource reduction, Reuse and Substitute [3] [32]. The prevention aspect deals with the prevention of any unnecessary energy wastage because of the unnecessary manufacturing operations. These help in finding for instance, when equipment’s can be stopped when they are not in use etc. But for identifying this, there has to be a great collaboration between all the sections in the manufacturing for processing varied data collected from them to identify any unnecessary operations or extra operations. These data sets have to be collected from many functions which may include, data of the production schedule could be collected from planning department, data for resources could be collected from facilities management etc. Waste reduction is generally focused on the waste outputs for the reduction of losses and waste in the supply chain. The manufacturers have a limited awareness of the output waste and thus for identifying waste patterns, manufacturers have to gain through data collection.

Reduction of the resource use is another way of reduction in energy in manufacturing. This generally focuses on the Inputs in the manufacturing to increase the efficiency of the processes. High difficulties could arise in altering the production schedule as it requires deep knowledge and understanding of the entire production process. Reuse on the other hand is also one of many important tactics to reduce the energy reductions in the manufacturing system. It mainly focuses on the flow of waste throughout the manufacturing process and the whole chain in finding ways and opportunities to reuse the output waste and converting it to input resource in the manufacturing process.

Substitution is also one of the many techniques which help in the reduction of energy and making manufacturing more sustainable. This process can be made to identify in the early stages of the modeling process, the components which are inefficient on the basis of the efficiency, capacity, age, process etc. This tactic could be generally found in the industry as they identify any process or equipment and replace or substitute it with a more efficient and comparatively less environmentally harmful one and intern increase the performance of the sustainability in the manufacturing process.

Similar to the above techniques, Toyota has developed its own energy reduction techniques which have been very successful [15][32]. These techniques have helped them to reduce a significant amount of energy reductions and are also being used commercially in many companies [38]. The major consideration that they have taken was to reduce the CO₂ emissions right from the manufacturing processes, which included very keen consideration of the varied production processes to match with the production fluctuations levels, reduction in the facilities, improvements in the operating rates etc. All these methods are coupled into main six attributes which represents the varied actions that are taken to assist with the reduction in energy consumption.

These six attributes include Stop, Repair, Reduce, Pickup and Change. The first attribute (stop) represents the elimination of stand still processes which consume energy and not performing any operation. The second attribute (Repair) concerns with the energy lost during a breakdown. The third attribute (Reduce) deals with the excess amount of energy consumption due to excess or non-productive operations. The fourth attribute (Pickup) is concerned with the recycle concept in the manufacturing supply chain, it reasons which are the products that could be recycled and reused. The fifth attribute (Change) is the need to improvement in the manufacturing processes and technology in an effort to reduce the energy consumption in manufacturing [1] [26] [34].

In an operations perspective, the energy reduction activities can be divided into three categories which include. In category one, focus is given more to the reduction of energy in the periods where the production is off, these may include the first (Stop) and second (reduce) attributes. The second stage is more focused on the reduction of energy reduction activities in the fixed energy in the operation, this could include the third (repair) and fourth (reduce) attributes. Only
after going through CPDCA (Check, Plan, Do, Check and Act) cycle it is feasible to move on to the third stage. In the third stage, it is focused on energy reductions through the advanced improvement in the equipment’s and efficient machining operations [34]. All of these attributes and steps were implemented in Toyota and were very successful in performing energy reductions.

V. REALIZING THE NEED FOR GREEN PERFORMANCE MEASUREMENT

The need for measuring quantitatively the environmental impact by the manufacturing processes is highly required. The manufacturing processes and techniques should be implemented keeping in mind the environmental consequences it will have on the long term as well as short impacts on the eco system and realize the benefits of the potential improvements. Many researchers have developed different tools which accesses and measures the performance of the manufacturing processes in many ways, but there is a gap in developing technique for considering all the aspects for all the flow of resource throughout the supply chain and in the manufacturing process [1][32]. Also these techniques or tools are very complex and need very complex data processing.

When considering lean approaches, the tools and methodologies which are developed needs large improvements and refining. Also these have to include all the aspects in the manufacturing operation [4]. A decent amount of research has been carried out in developing performance measurement tools. For instance, a performance measurement system which was dependent upon the following criterion, Effectiveness, which is basically defined as the actual output by expected output. Efficiency, which is the expected resource consumed to the actual resource consumed. Quality (It deals with downstream system, input, output, up and down stream, value adding processes and operations), innovation (an important aspect to consider when measuring performance), Productivity (it is the measure of the output to the input). These aspects which were considered had some flaws; these were not directly affecting the environmental aspect of the manufacturing systems and operations and have to be more environmental oriented as well [4][11][36].

Another Measurement tool was proposed in which four different methodologies were combined in an effort to improve measure and monitor the environmental performance [32]. These methods were internal audits in a form of questionnaires, external audits which included interference of third party experts, Self-assessments, which included many numerous continuous improvement approaches and benchmarking. These approaches address the environmental performance along the three dimensions as shown in Fig.5

Fig.5 Performance measurement along the three dimensions in the manufacturing system

Another performance measurement tool namely ENAPS which is European Network for Advanced Performance Studies was proposed by SINTEF and has environmental aspect in its core. It also incorporated reuse, recycle and substitute concepts its model [39]. This performance measuring system emphasizes not only to the environmental aspects but also to the business as a whole.

VI. GREEN PERFORMANCE MEASUREMENT INDICATORS

These indicators must cover every area of the business performance, making considerations for the environmental aspect to give enough information to the management for making the right decisions [34]. Also it has to be taken into account that while designing these environmental measures, they should not include unwanted information which may hinder the decision making process by making a balanced between the total coverage and scope of the business and the focus and aim of the measures [3]. Furthermore these measures should be designed for the individual enterprises. Thus the following measures were developed through research and extensive surveys and validations from which the enterprise could select from, in designing environmental measurement system which will monitor its environmental performance as shown in Table.1. However this does not mean that the enterprise should select all of them, but they should choose with respect to their own criteria. Also it has to be noted that this performance measurement system is not a constant entity but will change with respect to the changes and needs of the measurement system for that enterprises.

The following indicators are of strategic point of view and will help in setting the direction

- Environmental policy: This measure emphasizes on the existence and of an environmental policy implemented in an enterprise. This not only includes wildlife or nature but also quality of life as well.
- Environmental Consciousness: This measure is not only concerned with the awareness of the environmental sustainability in the establishment but also a mindset where everyone is motivated to minimize any harmful effects on the environment.
- Environmental Improvements: It is the efforts put by the organization in improving or repairing the harm caused on the environment.
• Quality of environmental life: It deals with the establishment in areas which are already vulnerable to the pollution or the extermination of vegetation or wildlife, or the worsening of the quality of life.

The following performance indicators focus mainly on the operational level of the enterprise.
• Supplier’s Environmental policy: This indicator focuses on the suppliers take on the environmental implementation.
• Level of Environmental effects by the supplier: It deals with the pollution, energy use and resources which are replaceable and waste levels of the supplier.
• Harmful Goods: It deals with the harmful and environmentally dangerous goods which are purchased by the suppliers.
• The 3R Concepts: It deals with the level of implementation of Reuse, Remanufacture and Recycle concepts by the suppliers.

The following performance indicators concentrate more on the operational level of the enterprise.
• Waste: The amount of waste which is produced or in connection to the enterprise.
• Pollution: The amount of pollution which is discarded into the sea, land and air.
• Energy: The amount of energy which is consumed.
• Resources: The amount of the resources which are irreplaceable.

PERFORMANCE MEASURES THROUGH THREE SUSTAINABILITY PERSPECTIVES:

The following performance measures are with respect to three perspectives in sustainability, which are environment, economic and social perspective as shown in Table.1.

Environmental Perspective: In this aspect of the sustainable measures deals directly with the environmental preservation. These measures may include as follows
• Environmental process improvement: This measure deals with the amount of efforts by the enterprise in optimizing and improving the operations and the processes in minimizing the environmental impact. This measure may include reduction of waste, pollution control etc.

• Environmental Products: This measure makes sure that the final product or the resources specifications and characteristics do not effect in any way in degrading the environment. This measure may include eco labeling, design for assembly etc.
• Environmental Recycling: This measure allows analyzing the level of recycling processes which may include time for recycling, energy consumed etc. as can be seen in Fig.6. This measure may include waste during recycling etc.
• Environmental Technology Improvements: As the name suggest the measure deals with the improvements or the introduction of new technology for the improvement of the environmental impact. This measure may include the introduction of new processes etc.

Economic Perspective: The following measures deals with economic aspect in the enterprise sustainability. This aspect may include the following measures.
• Environmental Expenses: This measure help in analyzing the net or the total amount which in invested in making the enterprise environmental friendly and sustainable. This measure may include recycling costs, disposal costs etc.
• Environmental traditional costs: This measure includes the regular costs which deal with the normal operations which are used to assess in comparison with the environmental expenses. This measure may include cost of delivery, inventory costs etc.
• Environmental Quality: This measure deals with the product standard and quality. This may include customer complains, warranty etc.
• Environmental Flexibility: This measure the ability of the enterprise to adjust to the upcoming changes to the operations and processes. This may include flexibility in production, flexibility in delivery etc.
• Environmental Responsiveness: This measures the responsiveness at which it adjusts to the changing processes and operations. It may include Lead time etc.

Social Perspective: The following measures deals with the Social aspect of the enterprises sustainability. This may include the following measures.
• Environmental Commitment: This measure deals with the responsibility of the enterprises management in making sure that the environmental sustainability is intake with biasness regardless of the selection of the suppliers etc. This may include number of environmental management initiatives etc.
• Environmental Customer Satisfaction: This measure deals with the customer opinions for the environmental and sustainable operations and processes. This may include interests of customer

![Fig.6 Reverse Supply Chain Management](image-url)
in sustainable products, Satisfaction of the customers towards the green products etc.

- Environmental Development of Employees: This measures the employee’s involvement in the practice of environmental sustainability in the enterprise. This may include environmental programs for the employees etc.

Table 1 Green Performance Measurement Indicators with different perspective, measures, metrics and references respectively

<table>
<thead>
<tr>
<th>S.no</th>
<th>Performance Perspective</th>
<th>Measures</th>
<th>Metric</th>
<th>References</th>
</tr>
</thead>
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<td>Strategic Level Measures</td>
<td>Environmental policy</td>
<td>ISO 14000 Implementation</td>
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<td></td>
<td>Environmental Consciousness</td>
<td>Management understanding of Sustainability</td>
<td>[2] [18] [13]</td>
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<tr>
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<td></td>
<td>Environmental Improvement</td>
<td>Number of steps taken for environmental improvement</td>
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<td></td>
<td></td>
<td>Quality of Green Life</td>
<td>No of establishments effecting vegetation and wildlife</td>
<td>[5] [29]</td>
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<td>1(b)</td>
<td>Tactical Level Measures</td>
<td>Suppliers Environmental Policy</td>
<td>No of suppliers having ISO 14000</td>
<td>[29] [37] [38]</td>
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<td></td>
<td></td>
<td>Harmful Environmental effects</td>
<td>Energy usage and pollution levels of the suppliers</td>
<td>[3] [25] [28]</td>
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<td></td>
<td></td>
<td>Harmful Resources</td>
<td>Harmful goods purchased by the suppliers</td>
<td>[11] [39]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The 3R Concepts</td>
<td>Level of implementation of Recycling, Reuse and Remanufacturing by supplier</td>
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<td>Operational Level Measures</td>
<td>Waste</td>
<td>Amount of waste produces</td>
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<td></td>
<td></td>
<td>Pollution</td>
<td>Amount of pollution emitted</td>
<td>[16] [13]</td>
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<tr>
<td></td>
<td></td>
<td>Energy</td>
<td>Amount of energy which is used</td>
<td>[17] [18] [40]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resources</td>
<td>Amount of harmful resources which are used</td>
<td>[10] [14]</td>
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<td>Environmental Process Improvement</td>
<td>Number of Waste reduction initiatives</td>
<td>[3] [19]</td>
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<tr>
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<td>Environmental Products</td>
<td>Eco-labeling</td>
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<td>[4] [30]</td>
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<td>Level of Recycling</td>
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<td>[23] [36]</td>
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<td></td>
<td>Environmental Technology</td>
<td>No of introduction of improved environmental friendly processes</td>
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<td>[37] [39]</td>
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<td>Economic Aspect</td>
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<td>Recycling Cost, Disposal cost etc.</td>
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<td></td>
<td>Environmental Traditional Cost</td>
<td>Cost of delivery, Inventory cost etc.</td>
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<td>[4] [14]</td>
</tr>
<tr>
<td></td>
<td>Environmental Quality</td>
<td>Number of customer complains etc.</td>
<td></td>
<td>[3] [13]</td>
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<td></td>
<td>Environmental Flexibility</td>
<td>Flexibility in delivery, production etc.</td>
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<td>[34] [35]</td>
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<td></td>
<td>Environmental Responsiveness</td>
<td>Lead Time</td>
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<td>[3] [16] [25]</td>
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<td>2(c)</td>
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<td>Customers awareness and satisfaction towards green products</td>
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<td>[9] [34]</td>
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<td>Number of Environmental programs for the employees</td>
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<td>[39]</td>
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<td>Number of suppliers having Environmental Certification</td>
<td>[2] [18]</td>
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<td></td>
<td>Environmental Design</td>
<td>Amount of hazardous materials in product manufacture</td>
<td></td>
<td>[2] [4] [33]</td>
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<tr>
<td></td>
<td>Environmental Manufacturing</td>
<td>Remanufacturing Initiatives</td>
<td></td>
<td>[3] [19]</td>
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<tr>
<td></td>
<td>Environmental Distribution</td>
<td>Amount of CO₂ Produced in Distribution</td>
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<td>[6] [39]</td>
</tr>
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<td></td>
<td>Reverse Logistics</td>
<td>Amount of used product which is reused and recycled</td>
<td></td>
<td>[1] [32]</td>
</tr>
</tbody>
</table>
GREEN SUPPLY CHAIN MANAGEMENT
PERFORMANCE INDICATORS:

Zhu & Sarkis [3] [24], Srinivastava [1] has defined a Green supply chain management as the integration of environmental consideration or consciousness into the supply chain, which may include the service and product design, procurement, manufacturing operations and processes, product distribution and the product’s end of life cycle management for making the enterprise more environmentally and sustainably competitive. The green supply chain management performance indicators may be divided into Environmental purchasing [2] [18], Environmental Design [2] [38], Environmental Manufacturing [3] [19] [39], Environmental Distribution [6] [39], Reverse logistics [32].

- Environmental Purchasing: This measure deals with the environmentally conscious purchasing, which makes sure that the materials which are purchased should meet the green and environmental standards which are established by the organization or enterprise. These may include the filtration of the suppliers which are certified with ISO 14000, reuse, recycle in the purchasing aspect etc [37] [38].
- Environmental Design: This measures the issues which are related to the environmental conscious design processes throughout the life cycle including the aspect of reduce, reuse and remanufacturing (The three R’s). This measure may include product design while making sure the production process is environmental friendly, not using hazardous materials in making products etc [3] [39].
- Environmental Manufacturing: This measures deals with the reduction of processes in manufacturing which are harmful to the environment. This measure includes concepts including reuse, remanufacture and recycle advancements in the manufacturing technology keeping in mind the environmental aspects etc [3] [19].
- Environmental Distribution: This measure deals with the integration of environmental concepts in transportation, packaging and the logistics activities. This measure includes reduction of CO₂ emissions in the transportation and distribution of products, the usage of environmental friendly products in packaging etc [6] [39].
- Reverse logistics: This measure includes the implementation of reuse, recycling and remanufacturing concepts in the enterprise. This measure includes the amount of used products which is recycled, the amount of products which is remanufactured etc [4].

VII. CONCLUSION

In this research paper, the manufacturing and machine tool systems energy efficiency applications have been analyzed and discussed. The study indicates that any improvement of the environmental aspects in manufacturing can only be done with consideration of both the aspects from machine tool to manufacturing. The enhancements on the machine tool level can be highly improved if it is coupled with the enhancements made on the manufacturing operations and process levels. Thus these two concepts have to be considered simultaneously to improve environmental efficiency. Environmental implementation, barriers and their remedies are also elucidated.

This paper has also developed the environmental performance measurement indicators, modeled on strategic, tactical and operational level in the enterprise. The second sets of indicators are developed based on the three perspectives namely environmental, economic and social aspects of the sustainability in the enterprise. The third sets of indicators were developed from a green supply chain perspective to ensure a better control for the enterprise management to analyze the effects of these aspects on the environmental or sustainable performance on the supply chain level.

These measures will help in improving the environmental performance in the organization by the implementation of the environmental performance measurement system, which will help the management in making an informed decision and in making any strategies for environmental improvement in the organization.

It is also found that the need for the enterprises to undertake operations in an environmental conscious perspective is highly needed not only for the environmental benefits but also for the enterprises competitiveness. Thus in this paper it is suggested that if the enterprise have to improve its environmental performance then it requires the means to measure and monitor its environmental status and thus derive solutions to improve it with the information derived from it. This paper also proposes the Green Performance indicators for the enterprises green performance measurement system throughout the enterprises dimensions.

This paper also suggests that the manufacturers should realize the importance of environmental processes and operations, not just for the sake of environmental safety but also for their competitiveness and thus implement green performance measurement systems in their enterprise.

FUTURE SCOPE

This paper also suggested a perspective to future research. A detailed study needs to be undertaken, to know which performance measures
or practices are more important and advantageous than the others. These practices should be executed keeping in mind the environmental sustainability of the enterprise. This will help the enterprise in prioritizing and making informed decisions after analyzing and selecting all the green performance measures and matrices.

REFERENCES


