



Vol. XIV &amp; Issue No. 12 December - 2021

INDUSTRIAL ENGINEERING JOURNAL

## SIGNIFICANCE OF GREEN MANUFACTURING TECHNOLOGY IN GLOBAL MANUFACTURING SCENARIO- A REVIEW

Dr. Maheswar C Y

Dr. Mahantesh S Tattimani

Dr. Babu Reddy

### Abstract:

*Manufacturing industry around the globe has witnessed different trends from Industry 1.0 to Industry 4.0. The transformation is happening at a normal pace, but the trend is now shifting towards reducing the environmental impacts of manufacturing because of its long term repercussions. Several tools and techniques namely benchmarking, Just-in-time, flexible manufacturing emerged in past with a narrow scope on addressing some aspects of manufacturing, but green manufacturing encapsulates many aspects of manufacturing under one umbrella. Green Manufacturing (GM) focuses on reduction of wastage, resource utilization efficiency, energy conservation and ecology restoration. This paper provides a review of literature on certain aspects of green manufacturing such as need for green manufacturing, advantages and limitations associated with it and drivers and barriers of green manufacturing implementation. It also addresses the significance of green manufacturing in current global manufacturing setting at large.*

**Keywords:** Benchmarking, Just-in-time, green manufacturing, energy conservation, ecology restoration

### 1. INTRODUCTION

The manufacturing sector has significantly contributed to global economic growth and the trend is continuing till date. Manufacturing industry has transformed from different stages from Industry 1.0 to Industry 4.0. In the early stages of manufacturing, the sole intention was to enhance the profits, improve the cash flows and in improving the productivity with least concern on the other aspects. Environmental concern of manufacturing was thought to be out of the scope of manufacturing during the early stages. Nevertheless, with the emergence of new tools and techniques namely Just-in-time (JIT), lean manufacturing, flexible manufacturing, benchmarking to name a few and the manufacturing industry adopted these practices to gain competitive edge.

Lean manufacturing essentially aims at reducing the different types of waste which in turn results in cost reduction and in providing value to customer. Some aspects of lean manufacturing are incorporated in green manufacturing with some additional focus on environmental effects of manufacturing. Green manufacturing is playing a significant role in manufacturing industry at global scale because of long term benefits associated with its implementation. Green manufacturing not only focus on waste reduction and better resource utilization, but it also focuses on reducing the environmental impacts of manufacturing at large which should be the order of the day. Gupta [1] pointed out that objective of green manufacturing is to design and produce product in an environmental benign manner. Therefore, green manufacturing intends to reduce the environmental impacts at all levels may it be air, water and noise and thereby improves the quality of life. Kothwade [2] reported that green manufacturing stresses on reducing parts, rationalizing materials and reusing the components to make products more efficient to build. Glinmine and Sangotra [3]

defined green manufacturing as a system that integrates product and process issues with issues of manufacturing and control in such a manner to identify, quantify, assess and manage flow of environmental waste with the goal of reducing and ultimately reducing environmental impact while trying to maximize the resource efficiency. Melnyk and Smith [4] defined green manufacturing (GM) as “a system that integrates product and process design issues with issues of manufacturing planning and control in such a manner to identify, quantify, assess, and manage the flow of environmental waste with the goal of reducing and ultimately minimizing environmental impact while trying to maximize resource efficiency”. The term green manufacturing was coined to reflect the new manufacturing paradigm that employs various green strategies (objectives and principles) and techniques (technology and innovations) to become more eco-efficient, this includes creating products/systems that consumes less material and energy, substituting input materials (e.g. non-toxic for toxic, renewable for non-renewable), reducing unwanted outputs and converting outputs to inputs (recycling) [5]. Tan et. al., [6] stated that green manufacturing integrates manufacturing-related environmental issues to mitigate adverse environmental impacts and resource consumption throughout the product lifecycle, that is, from product design, synthesis, processing, packaging, transportation and use to recycling.

### 2. NEED FOR IMPLEMENTATION OF GREEN MANUFACTURING

Green manufacturing aims to address the issues of manufacturing on global scale, the identification of such issues are equally important and relevant. Garbie [7] proposed that many companies have potential to grow rapidly due to economic growth and employee productivity, nevertheless in the process of growth, natural resources are depleted, resulting

in environmental effects through emission and pollution. It is quite evident that energy consumption, temperature, CO<sub>2</sub> levels, potential effects of industrialization is increasing at an alarming rate globally due to industrial activities. It is high time for the manufacturing sector to get prepared to identify and resolve such issues. Although some countries such as United States, United Kingdom and Germany have taken serious steps to enforce regulations by means of penalties to reduce the greenhouse emissions as a first step to reduce global warming.

Assessment and evaluation of energy-mix in manufacturing is crucial from long term perspective. The right energy-mix results in providing fruitful results from resource conservation and environment impact point of view. Malhotra and Kumar [8] defined green manufacturing as a method which minimizes wastes and pollution with a goal of utilizing minimum natural resources and retaining them for future generations. Qureshi et.al, [9] reported that green manufacturing provides tools and techniques to protect environment but the focus is more towards environment when compared to sustainable manufacturing paradigm which is based on triple bottom line i.e. economy, environment and society. Belekar [10] pointed out that green manufacturing is a term used to describe manufacturing process that do not harm environment during any part of the process. Green manufacturing system reflects the process of energy consumption and emission. It is an integrated system composed of energy equipment, energy medium, materials, intermediate products, final products and emissions [11]. Today environmental manufacturing is becoming a strategic approach in recent business endeavours, furthermore, due to increase in social and political pressure now organizations are shifting from profit driven strategies to green manufacturing strategies which are also becoming a source of competitive advantage [12]. Green manufacturing addresses a number of manufacturing matters, including recycling, conservation, waste management, water supply, environmental protection, regulatory compliance, pollution control, and a variety of other related issues [13]. The need to reduce toxicity through recycling, waste and minimization of hazardous by-products are driving businesses to adopt green manufacturing practices [14]. Current competitive environment compels companies on enhancing business and environmental performance, superior performance leads to the competitiveness and in order to stay competitive, it is expected that manufacturing companies must remain alert and must regularly evaluate their performance considering green challenges and therefore Indian manufacturing industries are shifting forward from “conformance to performance” and are serious towards comprehensive green manufacturing rather than just pollution prevention [15]. The rapid depletion of natural resources, growing energy demand, increasing customer awareness about environmentally conscious products and need for compliance with environmental legislation through development of green processes led to the evolution of a green manufacturing paradigm [16]. Green manufacturing focuses on issues which are multi-dimensional in nature ranging from sustainability to environmental to ecological to name a few. Green manufacturing covers a wide range of environmental and sustainability issues including resource material selection,

transportation, manufacturing process, pollution, and so on [17]. Increasing concern about the environment has forced industry to innovate and reduce its environmental impact; future global manufacturing is no longer going to be the competition of capital, resources and labour power but the competition of green technology [18]. Increasing CO<sub>2</sub> concentration in the atmosphere leading to the greenhouse effect, deficiency of energy and natural resources, release of toxic material and waste generation during the manufacturing processes necessitated the development of a manufacturing paradigm with minimal adverse environmental effects; this led to the evolution of green manufacturing [19]. Green manufacturing leads to production efficiency lower raw material costs due to (i.e. recycling waste rather than purchasing virgin materials), reduced environmental and occupational safety expenses and improved corporate image [20]. Green manufacturing is an up-and-coming philosophy of manufacturing aims to reduce the impact on environment, by using materials that are eco-friendly and by avoiding or reducing pollution to the maximum extent; Green Manufacturing can be ensured and wherever possible the electric power can be produced with these renewable energy sources [21]. Going green in manufacturing will also improve the quality of the production process which will in turn impact product quality and also will be more appealing to the growing number of customers looking for green manufacturers and products [5]. Green Manufacturing initiatives evolve practices which aim to optimize the use of resources during the product life cycle; Companies aim to optimize production operations to obtain maximum asset efficiency [22].

As pointed out earlier, the energy-mix needs to be analysed seriously and identify the sources associated with it. If in case non-renewable sources such as coal are used, then the next step would be replace these with renewable sources such as Solar, Wind and Hydel which results in both reduction of environmental effects and conservation of resources.

### 3. DRIVERS AND BARRIERS OF IMPLEMENTATION OF GREEN MANUFACTURING

Green manufacturing is helping out the industries to attain the business goals in a sustainable manner; it has marked a new paradigm in the way of running business. There are several drivers and barriers during the implementation of green manufacturing and therefore the industries need to focus on these aspects during the process of implementation from long term perspective. Drivers which motivate green manufacturing in Malaysian SMEs are improved company image; improved competitiveness and enhanced product quality through green manufacturing and the critical barriers which hinder the implementation of green manufacturing in SMEs are weak organizational structure to support green manufacturing as well as inadequate R&D, design and testing within the organization to support green manufacturing [23]. The motivating factors for implementation of green manufacturing are regulatory mandates, economic advantage, conservation of energy, water, materials, product take-back system, corporate image, and employee satisfaction [24]. The common drivers of green manufacturing implementation include financial benefits, company image,

environmental conservation, compliance with regulations, stakeholders, green innovation, supply chain requirements, customers, employee demands, internal motivations, market trends, and competitors [25]. Top management commitment has highest driving power for the implementation of green manufacturing, effective implementation of green manufacturing will improve organization performance in terms of product cost and quality; for effective implementation of green manufacturing, management should not ignore people development, product and process development as well [26]. Top management commitment, technology up-gradation, current legislation, green brand image and future legislation are five most critical drivers of implementation [27]. Top management commitment, green procurement practices and societal concern for protection of natural environment are the most important enablers, and competitiveness and availability of clean technology have comparatively less importance with respect to green manufacturing implementation [28]. A case study carried out in an automobile manufacturing company, identified eco-design, green image, top management commitment, and use of environment-friendly raw material as drivers of green manufacturing practices [29]. The key elements of green manufacturing include top management commitment, employee involvement, training green product/process design, supplier management, and measurement and information management [30]. The need for adherence to environmental compliance regulation is driving companies/businesses to adopt green manufacturing [31]. The barriers of green manufacturing are lack of data, technical expertise, infrastructure, and capital resources, for low implementation of green manufacturing practices by SMEs [32]. Lack of innovation in the manufacturing process is considered the kingpin of barriers in GM implementation as all secondary barriers are the result of failure in innovation [33]. Wakeford et al., (2017) carried out a survey in 117 firms and the result revealed expensive technology, lack of financial support, and meagre information as the barriers to green manufacturing practices [34]. The barriers of implementing green manufacturing practices in Indian SMEs, the five most critical barriers are lack of research and development (R&D), failure in eco-design, lack of accreditation, poor supply chain management and absence of market diversification [35].

#### 4. ADVANTAGES AND LIMITATIONS ASSOCIATED WITH GREEN MANUFACTURING

Green manufacturing is a technology that aims at providing long term benefits to the implementing organization. Although initially costs are incurred in developing appropriate strategies in terms of installation of equipments for reducing environmental impacts, these costs however will be recovered in due course of time. Nevertheless green manufacturing is bounded by certain limitation such as implementation cost, technological and managerial barrier etc. Irarvani et.al, [36] identified the advantages of green manufacturing as : reduction in Green House Gas emissions (GHG), conservation of resources and energy, reduction in operational cost, improvement in air and water quality etc and pointed out some of limitations associated

with green manufacturing as: high implementation costs, political and technical barrier and lack of skilled personnel. Bharadwaj and Neelam [37] highlighted the advantages and disadvantages of green manufacturing from their study, the main advantages associated with green manufacturing are emission reduction, economic benefits and use of renewable source and reduction of global warming, while the disadvantages pointed out were high implementation cost, lack of infrastructure, lack of alternative process technology and lack of alternative raw-material input. Green manufacturing applications have a significant positive impact on environmental performance and social performance, additionally; eco-process innovation has a significant positive impact on corporate sustainability [38]. In all, green manufacturing results in cost reduction, focuses on conservation of energy and resources and restoring the ecology, all these aspects are crucial and is a global concern too.

It is understandable that the manufacturing needs to make a trade-off between the long term benefits of green manufacturing and cost aspects, so that the green manufacturing could be implemented in a judicious manner to gain long term benefits.

#### 5. SIGNIFICANCE OF GREEN MANUFACTURING

The current global trends in manufacturing require a serious tuning from ecological and environmental perspective. Green manufacturing addresses the environmental concern by taking into consideration the emissions and other pollution resulting from manufacturing companies. One of the promising approaches to creating a balance in ecosystem is through implementation of green manufacturing, the techniques of green manufacturing can be applied to reducing the pollution level, minimizes waste, facilitates financial development and marmalade reserves [39]. Green manufacturing also suggest the alternative energies that can be used otherwise such as cleaner energies (solar, wind, biomass) to reduce the environmental degradation. The use of cleaner and sustainable energy will reduce the long term implication on the environment and the resources could be conserved for the generations to come. A green manufacturing process involves a comprehensive and holistic approach that encompasses everything a business does those impacts the environment. Thus, it assists companies in making systematic changes in areas like product design, emissions, tools, trends, energy, transportation, water and waste [40]. Green manufacturing creates a reputation to public, saves useless cost and promotes research and design, the process of green Manufacturing involves investing in production process improvements rather than control technology, substitute renewable sources for finite ones, employee recycling and the companies must decide whether to make or buy the product [41].

The appropriate energy-mix should be considered both for both phases, production as well as the use phases of the product, so that it can be replaced by cleaner and sustainable source of energy. It is well known fact that the manufacturing process is complex in nature involving different activities and it is energy intensive. The focus of green manufacturing is to conserve the energy in different phases of manufacturing and conserve the resources such as raw-materials, work-in-process and finished



goods as well as consumables used such as lubricants, coolants and so on. Green manufacturing encompasses all factors associated with environmental concerns in manufacturing by continuously integrating eco-friendly industrial processes and products [42]. Green manufacturing takes into consideration the life cycle cost of products being manufactured along the different phases of supply chain. Green manufacturing has been pursued as a means of eco efficiency, which represents the concept of creating more goods and services while using fewer resources and creating less waste and pollution [43]. Green Manufacturing involves not just the use of environmental design of products, use of environmentally friendly raw materials, but also eco-friendly packing, distribution, and destruction or reuse after the lifetime of the product [44]. Manufacturing enterprises with strong green technology innovation ability can not only introduce green manufacturing products and services with high added value to meet the needs of consumers, reduce the green cost of enterprises and improve the contribution rate of technological innovation to profits, it can also improve the enterprise's ability to deal with technical risks and the full capacity of the green wall [45]. Green practices don't generally make a weight for industry. Customary green practices which have diminished waste and improved industry results should now be taken to vital core interest, straightforward difference in existing items and improving operational efficiencies should now offer path to an authority centered green vital methodology towards the earth [46]. Increased industrialization has led to growth in waste and e-waste generation, pollution due to ineffective waste disposal, GHG emission, and improper disposal of industrial effluents due to meet the growing demand of population, transforming to green manufacturing by shifting towards green energy, products and processes can help to meet this sustainability challenge [47]. A green technology innovation system includes the innovation subject, the innovation environment, the innovation resources, the innovation infrastructure, and various other elements [48]. In addition to the environmental and social benefits, green manufacturing systems also provide direct economical benefits in term to reduced supply chain costs; material and energy costs; waste treatment, categorisation, storage and handling costs; maintenance, use and service costs, it also provides indirect benefits in term of improved employee safety, health, morale and motivation; customer loyalty and satisfaction [49]. Green technology is the regeneration of production processes and the creation within the industrial sector of environmentally friendly operations. Environmental development includes three methods of changing manufacturing activities: utilizing green energy, producing and marketing renewable goods and, using green technologies in business operations [50]. Green product and process development is an important first step towards sustainability. Uncertainty in operational lead times and financial investments can often lead to costly and unwanted outcomes; which may be at least partially avoided through investing in sustainable technologies [51]. Manufacturers in the countries with high research and development capabilities can reduce carbon emissions and improve environmental productivity at the same time [52].

Even though the manufacturing industry acted as catalyst to boost global economic growth, nevertheless the environmental effects associated with it is a serious concern which requires immediate attention. These problems call for an assessment and that is how green manufacturing come into existence. The green manufacturing is wider in scope and takes into consideration several essentials of manufacturing simultaneously and produce long term positive impact on the manufacturing industry. Green manufacturing if implemented judiciously results in better resource utilization, reduction in operational cost, reduce pollution and restores the ecology which is of a greater concern.

## 6. CONCLUSIONS

It is clear from the discussions that green manufacturing results in improving the environmental situation on a global scale. Green manufacturing although incurs some initial cost for installation of equipments as a preventive measure against environmental pollution, it provides benefits in the long run. Green manufacturing not only addresses the environmental issues, but it results in conserving energy, resources and materials which are all of great concern irrespective of the nature and type of the firm. Organizations implementing green manufacturing should adopt appropriate strategies to reap the long term benefits of implementation. Green manufacturing implementation strategies are long term in nature and therefore yield fruitful results over a period of time. Therefore, green manufacturing improves the quality of life at large as it takes care of environmental impacts and leads to the conservation of resources, material and energy which are all relevant from long term perspective. The implementation of green manufacturing yield long term positive impacts on economics, social and ecology at large which are all significant for any industry around the global to sustain, compete and to gain competitive edge in the global corporate setting as a whole.

## REFERENCES

1. M. Surendra Gupta, "Lean Manufacturing, Green Manufacturing and Sustainability", *J Jpn Manage Assoc*, 67, 102-105, 2016.
2. Nikhil Sudhir Kothawade, "Green Manufacturing: Solution for Indian Climate Change Commitment and Make in India Aspirations", *International Journal of Science and Research (IJSR)*, Volume 6 Issue 1, January 2017, pp.725-733.
3. V. Swapnil Ghinmine, Dilip I. Sangotra, "Implementation of Green Manufacturing in Industry - a case study", *International Journal of Research in Engineering and Technology*, Volume: 04 Issue: 04, Apr-2015, pp.42-45.
4. Melnyk, S.A., Smith, R.T., 1996. *Green Manufacturing*. SME Publication, Dearborn, MI.
5. Deif Ahmed, "A system model for green manufacturing", *Journal of Cleaner Production*. 19: 1553-1559, 2011.
6. Tan, X. C., F. Liu, H. J. Cao, and H. Zhang, "A Decision-making Framework Model of Cutting fluid Selection for

- Green Manufacturing and a Case Study*". *Journal of Materials Processing Technology* 129: 467–470, 2002.
7. H. Ibrahim Garbie, "Sustainability in Manufacturing Enterprises", Springer International Publishing, Switzerland, 2016.
  8. Vasdev Malhotra and Sameer Kumar, "The Techniques of Lean and Green Manufacturing Systems", *International Journal of Computational Intelligence Research*, Volume 13, Number 2 (2017), pp. 299-302.
  9. Muhammad Imran Qureshi, Amran Md.Rasli, Ahmad Jusoh, Tan Owee Kowang, "Sustainability: A New Manufacturing Paradigm", *Jurnal Teknologi (Sciences & Engineering)* (2015) 47-53.
  10. M. Aditya Belekar, "Green Manufacturing", *International Research Journal of Engineering and Technology (IRJET)*, Volume: 04, Issue: 07, July -2017.
  11. Xiangke Tian, Rongyong Zhao, Jian Wang, *The Multi-Levels Modeling to Green Manufacturing Energy System Using Multi-Agent Energy Hub*, IEEE 8th Joint International Information Technology and Artificial Intelligence Conference (ITAIC 2019).
  12. Chen TB, Chai LT. Attitude towards environment and green products: Consumers perspective. *Management Science and Engineering*. 2010 Mar; 4(2):27–39.
  13. Minhaj Ahemad Abdul Rehman, Rakesh L. Shrivastava. Development and validation of performance measures for green manufacturing (GM) practices in medium and small scale industries in Vidharbha region, India. *Int. J. Society Systems Science*, Vol. 5, No. 1, 2013
  14. A. Von Moltke, (2004), *The Use of Economic Instruments in Environmental Policy: Opportunities and Challenges*. UNEP/Earth print
  15. Rehman MA, Seth D, Shrivastava RL, Impact of green manufacturing practices on organisational performance in Indian context: An empirical study, *Journal of Cleaner Production* (2016)
  16. Nevil S. Gandhi, Shashank J. Thanki, Jitesh J. Thakkar, *Ranking of Drivers for Integrated Lean-Green Manufacturing for Indian Manufacturing SMEs*, *Journal of Cleaner Production* (2017).
  17. M. Hermann, T. Pentek, and B. Otto, "Design Principles for Industry 4.0 Scenarios: A Literature Review," Working Paper, TU Dortmund, Feb. 2015.8
  18. Mayank Dev Singh, G. D. Thakar. *Green Manufacturing Practices in SMEs of India-A Literature Review*, *Industrial Engineering Journal*, Vol. XI & Issue No. 3 March – 2018.
  19. Thanki S, Govindan K, Thakkar J, An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach, *Journal of Cleaner Production* (2016).
  20. Porter, M.E. and C. Van der Linde, *Green and competitive: ending the stalemate*. *Harvard business review*, 1995. 73(5): p. 120-134
  21. Dr. S. Nallusamy, K. Balakannan, G.B. Dinagaraj, S. Satheesh, *Sustainable green lean manufacturing practices in small scale industries - A case study*, *International Journal of Applied Engineering Research*, ISSN 0973-4562 Vol. 10 No.62 (2015)
  22. Rusinko, "Green Manufacturing: An Evaluation of Environmentally Sustainable Manufacturing Practices and Their Impact on Competitive Outcomes", *IEEE Transactions on Engineering Management*, vol. 54, no. 3, pp. 445–454, 2007.
  23. Raja Ariffin Raja Ghazilla<sup>1</sup>, Novita Sakundarini, Salwa Hanim Abdul-Rashid, Nor Syakirah Ayub, Ezutah Udoncy Ologu, S. Nurmaya Musa, *Drivers and barriers analysis for green manufacturing practices in Malaysian SMEs: A Preliminary Findings*, *Procedia CIRP* 26 ( 2015 ) 658 – 663.
  24. Gutowski, T., Murphy, C., Allen, D., Bauer, D., Bras, B., Piwonka, T., & Wolff, E. (2005). *Environmentally benign manufacturing: observations from Japan, Europe and the United States*. *Journal of Cleaner Production*, 13(1), 1-17.
  25. Kannan Govindan Ali Diabat, K. Madan Shankar, *Analyzing the drivers of green manufacturing with fuzzy approach*, *Journal of Cleaner Production* (2014) 1-12.
  26. Abhijeet K Digalwar, Nidhi Mundra, Ashok R Tagalpallewar, Vivek K Sunnapwar, (2017) "Road Map for The Implementation of Green Manufacturing Practices in Indian Manufacturing Industries.: An ISM approach", *Benchmarking: An International Journal*, Vol. 24 Issue: 5.
  27. Nevil S. Gandhi, Shashank J. Thanki, Jitesh J. Thakkar, *Ranking of Drivers for Integrated Lean-Green Manufacturing for Indian Manufacturing SMEs*, *Journal of Cleaner Production* (2017).
  28. Lalit K. Toke & Shyamkumar D. Kalpande (2017): A framework of enabler's relationship for implementation of green manufacturing in Indian context, *International Journal of Sustainable Development & World Ecology*
  29. Shen L, Olfat L, Govindan K, Khodaverdi R, Diabat A. (2013). *A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences*. *Resources, Conservation and Recycling*, 74, 170-179.
  30. Y. Wee, H.A. Quazi, *Development and validation of critical factors of environmental management*. *Industrial Management and Data Systems* 105(1), 96–114 (2005)
  31. S. X. Zeng, X. H. Meng, R. C. Zeng, C. M. Tam, V. W. Y. Tam, T. Jin, *How environmental management driving forces affect environmental and economic performance of SMES: A study in the northern China district*. *J. Clean. Prod.*, 19, 1426–1437, 2011.

32. Mittal, V. K., Egede, P., Herrmann, C., & Sangwan, K. S. (2013). *Comparison of drivers and barriers to green manufacturing: a case of India and Germany*. In *Re-engineering Manufacturing for Sustainability* (pp. 723-728). Springer, Singapore
33. Rodriguez JA, Wiengarten F. (2017). *The role of process innovativeness in the development of environmental innovativeness capability*. *Journal of Cleaner Production*, 142, 2423-2434
34. Wakeford JJ, Gebreyesus M, Ginbo T, Yimer K, Manzambi O, Okereke C, Mulugetta Y. (2017). *Innovation for green industrialisation: An empirical assessment of innovation in Ethiopia's cement, leather and textile sectors*. *Journal of Cleaner Production*, 166, 503-511.
35. Karuppiiah K, Sankaranarayanan B, Ali SM, Chowdhury P, Paul SK, *An integrated approach to modeling the barriers in implementing green manufacturing practices in SMEs*, *Journal of Cleaner Production* (2020).
36. Abolfazl Irvani, Mohammad Hasan akbari, Mahmood Zohoori, "Advantages and Disadvantages of Green Technology; Goals, Challenges and Strengths", *International Journal of Science and Engineering Applications*, Volume 6 Issue 09, 2017, pp.272-284.
37. Monu Bhardwaj, Neelam, "The Advantages and Disadvantages of Green Technology", *Journal of Basic and Applied Engineering Research*, Volume 2, Issue 22; October-December, 2015, pp. 1957-1960.
38. Bülent Sezen and Sibel Yıldız Çankaya, *Effects of green manufacturing and eco-innovation on sustainability performance*, *Procedia - Social and Behavioral Sciences* 99 (2013) 154 – 163
39. [39] Bhubaneswari Bisnoi, Divyajit Das, P Srinivas Subbarao, Biswajit Das, *An Evaluation on Green Manufacturing: It's Technique Significance and Reality*, *IOP Conf. Series: Materials Science and Engineering* 653 (2019).
40. Minhaj A.A. Rehman, R.L. Shrivastava, *Green manufacturing (GM): past, present and future (a state of art review)*, *World Review of Science, Technology and Sust. Development*, Vol. 10, Nos. 1/2/3, 2013.
41. G Dilip Maruthi , Rashmi R, *Green Manufacturing: It's Tools and Techniques that can be implemented in Manufacturing Sectors*, *Materials Today: Proceedings* 2 ( 2015 ) 3350 – 3355
42. Shan-Ping Chuang, Chang-Lin Yang, *Key success factors when implementing a green-manufacturing system*, *Production Planning & Control*, 2014, Vol. 25, No. 11, 923–937,
43. Ahn, SH., Chun, DM. & Chu, WS. *Perspective to green manufacturing and applications*. *Int. J. Precis. Eng. Manuf.* 14, 873–874 (2013)
44. Neha Verma, Vinay Sharma, *Energy Value Stream Mapping a Tool to develop Green Manufacturing*, *Procedia Engineering* 149 ( 2016 ) 526 – 534
45. Huiling Liu ,Dan, Ling, *Value chain reconstruction and sustainable development of green manufacturing industry*, *Sustainable Computing: Informatics and Systems* 28 (2020) 100418
46. Sarvesh P.S. Rajput, Suprabeet Datta, *Sustainable and green manufacturing – A narrative literature review*, *Materials Today: Proceedings* 26 (2020) 2515–2520
47. Nikhil Sudhir Kothawade, *Green Manufacturing: Solution for Indian Climate Change Commitment and Make in India Aspirations*, Volume 6 Issue 1, January 2017, pp:725-733
48. Shi Yin, Nan Zhang, Baizhou Li, *Improving the Effectiveness of Multi-Agent Cooperation for Green Manufacturing in China: A Theoretical Framework to Measure the Performance of Green Technology Innovation*, *Int. J. Environ. Res. Public Health* 2020, 17, 3211
49. Kuldip Singh Sangwan, *Development of a multi criteria decision model for justification of green manufacturing systems*, *Int. J. Green Economics*, Vol. 5, No. 3, 2011
50. S. Agarwal, V. Agrawal and J. K. Dixit, *Green manufacturing: A MCDM approach*, *Materials Today: Proceedings*
51. Alan D. Smith, *Green manufacturing in the packaging and materials industry: case study of small-to-medium sized corporate eco-friendly initiatives*, *Int. J. Logistics Systems and Management*, Vol. 11, No. 4, 2012, 429
52. Yan Li, Min Zhang, (2018) "Green manufacturing and environmental productivity growth", *Industrial Management & Data Systems*, Vol. 118 Issue: 6, pp.1303-1319

## AUTHORS

**Dr. Maheswar. C. Y.**, Asst. Professor, Department of Mechanical Engineering, Smt Kamala And Sri Venkappa M. Agadi College of Engineering & Technology (SKSVMACET), Lakshmeshwar, SH 6, Gadag, Karnataka – 582116  
Email: mahantesh.s.t@gmail.com

**Dr. Mahantesh. S. Tattimani**, Associate Professor, Department of Mechanical Engineering, Smt Kamala And Sri Venkappa M. Agadi College of Engineering & Technology (SKSVMACET), Lakshmeshwar, SH 6, Gadag, Karnataka – 582116  
(M) 099454 65050

**Dr. Babu Reddy**, Asst. Professor, Department of Mechanical Engineering, VTU's Centre for Postgraduate Studies, Kalaburagi - 585 105 (Karnataka)