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Strategies for assessment and implementation of sustainable manufacturing

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ABSTRACT

Manufacturing has been acknowledged for the intensive use of renewable raw materials, energy sources, and a significant contributor to pollutants causing multiple environmental issues and health hazards to the community. Sustainable manufacturing is a necessary prerequisite to conserve natural resources, mitigate the adverse impacts on environment, global economy, and society. It is important to identify and understand the implementation steps and the evaluation process for developing a sustainable manufacturing system. In this review, sustainable manufacturing has been described for better understanding of the concept. The insights about existing sustainability metrics with the inclusion of environmental, economic and social aspects of sustainability has been explored. The various sustainability indicators have been documented to provide an overview for sustainability assessment framework. In addition, the gaps in the existing sustainability metrics have been identified and the future goals for tailoring the current indicators has been explored. Thus, the study provides strategies for suitable sustainability assessment and action-plan for implementation of sustainable manufacturing.

Key words: Manufacturing; Sustainability; Environment; Economy; Society.

INTRODUCTION

The rapid increasing deforestation and the use of natural resources have given rise to significant environmental issues that have led to the need for sustainability that is fulfilling the needs of the current without jeopardizing the capacity of future generations to fulfil their own needs (Lami & Mecca, 2021). In addition, intensive industrialization has resulted in various social, financial, and environmental issues due to ineffective utilization of capital resources. The critical social issues involve health, safety, and quality of life whereas financial issues involve production cost, unemployment and business opportunities for human beings (Beng & Omar, 2014). The environmental issues related to the global warming, availability of pollution free environment and maintenance of ecological balance are of prime concern. The concept of sustainability is based upon addressing these issues by innovative and smart approach (Jung *et al.*, 2018).

In the current era, manufacturing is a source of goods and resources essential for all day-to-day activities involving living, health, and safety of human beings and significantly impact the global economy (Ahmad *et al.*, 2018). However, manufacturing is not limited to only the production process but is a chain of various processes right from the production using raw material and ends at consumption and disposal process. While production processes aid to financial gain, the consumption of a lot of resources with the production of waste is a matter of concern (Ahmad *et al.*, 2019). The waste produced, during the processing process, during the product use, and after the end of the product life, is responsible for environmental degradation (Pinto *et al.*, 2020). Thus, it becomes increasingly important to

mitigate the resource use and reduce the environmental effects of production processes (Pereira *et al.*, 2019). Hence, a sustainability approach is necessary for long-run manufacturing operations in the context of the environment and economic perspective. (Akbar & Irohara, 2018).

The concept of "sustainable manufacturing" applies to all operations in the manufacturing units including all intermediate measures related to manufacturing resources and services (Sudusinghe & Seuring, 2020). Literature reports that consumers can afford to invest additional funds if better products are offered by the production units (Zhou *et al.*, 2016). Thus, sustainable production can be an important approach for fostering improved financial results in addition to achieving social and environmental goals as illustrated in Figure 1. Consequently, industries must aim for sustainable manufacturing on their side. The sustainable use of natural resources and energy efficient processes can not only deliver desired services with improved products but can also ensure the health and safety of all participants (Murakami *et al.*, 2020). Therefore, there is an emerging need for a global initiative to practice sustainability in various industries and organizations (Jawahir *et al.*, 2015).

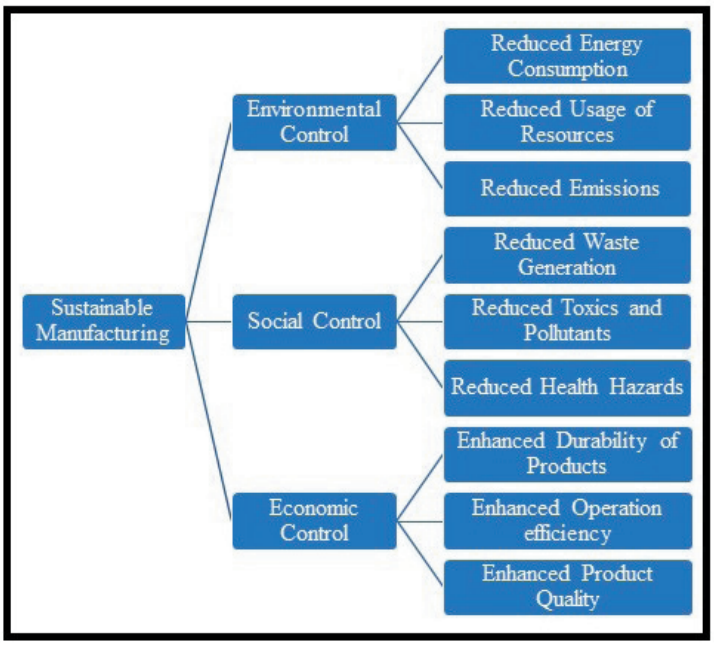

Figure 1. Concept of Sustainable Manufacturing

However, the global conceptualization and integration of sustainable manufacturing still require bridging the theoretical and practical approaches with resolution of the incurring financial, social and environmental issues (Abualfaraa *et al.*, 2020). In this regard, sustainability metrics including the suitable indicators is highly desirable to access the sustainable manufacturing approach used by the industrial units. Literature reports that the sustainability metrics developed by various organizations are varied but connect to the ultimate goal of sustainability (Ahmad *et al.*, 2019). For example, the Organization for Economic Cooperation and Development (OECD) specified 50 core environmental indicators to assess environmental effects of industrial practices in developed countries, while the UN Commission on Sustainable Development defined 92 indicators to address environmental degradation due to human activities (Rosen & Kishawy, 2012).

This paper is a comprehensive study aimed to provide a conceptual framework in terms of sustainable prospective for social, economic, and environmental management. The sustainability indicators including environmental, social

and economic indicators as per existing literature have been explored in section 2. The future goals for sustainability assessment in order to fill the gaps in existing framework have been explored in the subsequent section with concluding remarks.

SUSTAINABILITY INDICATORS

There has been an increasing pressure of environmental and social impact on manufacturing in addition to economic gains. Hence, manufacturers are looking forward to encouraging production practices that preserve the economic benefits with minimal environmental and social effects (Huang & Badurdeen, 2017). Also, with growing customer and employee awareness, desire for sustainable culture has led the global industries to adopt sustainable manufacturing strategies in the current competitive economic environment (Garza-Reyes, 2015).

Literature reports few appropriate assessment tools based upon some metrics for assessing sustainability and determining the environmental and social impacts of production (Ahmad *et al.*, 2019; Wu & Su, 2020). However, there is no uniformity on taxonomy of sustainability metrics and industrial units need to consider appropriate measures and indicators for achieving the goals of sustainable processes and products (Chaim *et al.*, 2018). In general, the list of indicators prescribed by various systems is very exhaustive and it is very difficult to define and use comprehensive, standardized, and usable indicators for a sustainable manufacturing procedure (Singh *et al.*, 2007). Therefore, defining, categorizing, and summarizing an exhaustive collection of indicators and assessment techniques is highly desirable for modeling sustainability issues (Bui *et al.*, 2017). A thorough study of the literature reveals that the sustainability aspects of manufacturing systems (Figure 2) are mainly assessed by three main indicators as discussed ahead.

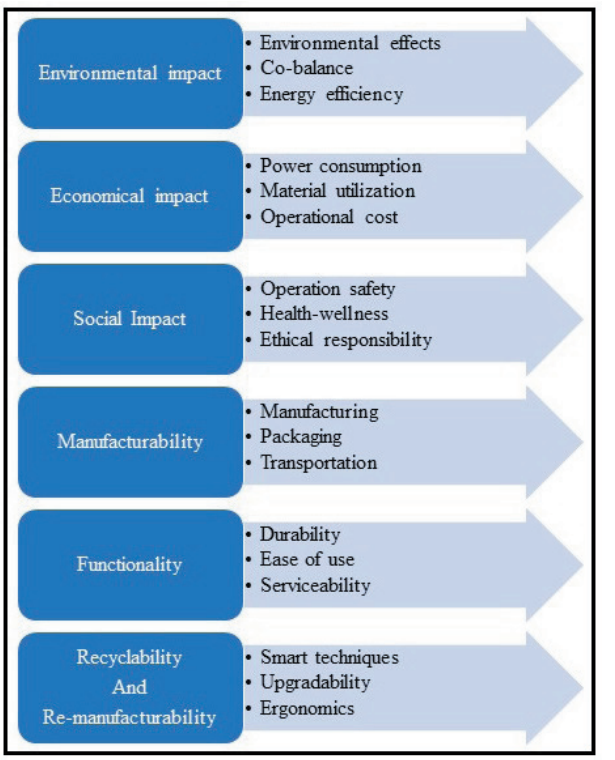

Figure 2. Key Factors for consideration in sustainable manufacturing

ENVIRONMENTAL INDICATORS

The environmental element of sustainability is focused on the principles of eco-system accommodation in terms of total energy resources as well as self-restoration limit with due consideration of the limited availability and continuous loss of natural resources (Lami & Mecca, 2021). The overuse and single line withdrawal of non-renewable as well as renewable resources beyond the recuperation period will ultimately result in the replenishment of resources (Ahmad *et al.*, 2019). The environmental indicators are the physical elements of sustainability and are generally referred to as the corporal measurements of longevity and are listed in Table 1. The prime focus lies on the consumption and efficacy of materials, natural and alternative sources including energy, water, and biomass, in addition to generation and recycling of waste and emissions (Abotalib *et al.*, 2021).

Table 1. Category, sub-category and indicators for Environmental Sustainability

Category	Sub-category	Indicator	References
Material	Non-renewable materials	Accessibility/ consumption/ efficacy/ recycle/reuse	(Ghobadian *et al.*, 2020)
	Renewable materials		(Sala, 2020)
	Hazardous materials		(Ahmad *et al.*, 2019)
Energy	Non-Renewable energy		(Akbar & Irohara, 2018)
	Renewable energy		(Cobut *et al.*, 2015)
Water	Input		(Joung *et al.*, 2013)
	Output		(Eastwood & Haapala, 2015)
Waste and emissions	Primary air pollutant	Disposal/reuse/recycle	(Chaim *et al.*, 2018)
	Secondary air pollutant		(Sala *et al.*, 2016)
	Solid waste		(Talens Peiró *et al.*, 2010)
	Liquid effluents		(Joung *et al.*, 2013)
	Climate gas emissions		(Golinska *et al.*, 2015)
	Volatile organic compounds		(Peralta Álvarez *et al.*, 2017)
	Noise pollution	Noise level	(Ahmad *et al.*, 2019)
	Heat generation	Amount	(Sala, 2020)
Logistics and reverse logistics	Packaging	Efficacy	(Jin *et al.*, 2017)
	Storage		
	Transportation		
Environmental conformance	Certificates	Labels/reports	(Bracke *et al.*, 2017)
	Sanctions	Venture	(Moktadir *et al.*, 2018)
	Fines	Spending	(Platcheck *et al.*, 2008)

ECONOMIC INDICATORS

Economic performance of any manufacturing unit is an important parameter that considers its economic success (Borchardt *et al.*, 2011). The contribution that industry provides to the sustainable economic environment, in which it works, is less commonly reported but also desired by readers of sustainability studies (Singh *et al.*, 2007). It is central to understanding the financial stability and the sustainable base of the unit and is generally reported in annual financial statements and statistics. However, the industry could be financially sustainable but may have been negatively influencing its stakeholders (Jawahir *et al.*, 2013). Hence, economic indicators are designed to assess the economic impact of industrial operations and their influence on a wide variety of stakeholders (Table 2). These indicators also reflect the outcomes obtained in handling the overall financial resources, its success, and strategies required for performance improvement as listed in Table 2.

Table 2. Category, sub-category and indicators for Economic Sustainability

Category	Sub-category	Indicator	References
Economic performance	Directly generated economic value	Revenue	(Bui *et al.*, 2017)
		Financial assistance	(Sala, 2020)
	Distributed economic value	Operating cost	(Chong *et al.*, 2018)
		Wages	(Boks, 2006)
		Debt payment	(Singh *et al.*, 2009)
		Taxes	(Moktadir *et al.*, 2018)
		Community investment	(Borchardt *et al.*, 2011)
	Retained economic value	Investment	(Boulanger, 2008)
		Equity release	(Nikolova, 2013)
Market viability	Competitive wages	Entry level distribution	(Boks, 2006)
		Senior level distribution	(Borchardt *et al.*, 2011)
	Viable practices	Local economy	(Boks, 2006)
Economic impact	Infrastructure	Community infrastructure	(Badurdeen & Jawahir, 2017)
	Direct impact	Financial transactions	(Moktadir *et al.*, 2018)
	Indirect impact	Socio-economic changes	(Badurdeen & Jawahir, 2017)

SOCIAL INDICATORS

The impact of various manufacturing processes and products on society is measured through social indicators involving various aspects with due consideration of safety and health of employees and customers along with any negative impact on the nearby community (Chaim *et al.*, 2018). Sustainable manufacturing requires the development and propagation of a vision of a socially sustainable workplace, with a safe, empowered, informed, and a willing workforce of all ages, gender, abilities, and stages of personal growth, to tackle the challenge of diminishing recruiting pool (Gebisa & Lemu, 2017). The concept of equality, empowerment, inclusion, engagement, sharing, cultural identity, and institutional cohesion is the foundation of the social dimension of sustainability (Henao *et al.*, 2017). It emphasizes society's solidarity and its ability to work towards shared objectives while addressing individual needs, such as health and well-being, nutrition, housing, education and cultural expression (Holm, 2018). These proactive visions will be vital to the potential growth of the industries, not only to ensure demographic continuity and employee fulfillment requirements but also to promote work-life balance and making efforts to promote welfare and development of all stakeholders. It also relies on improving customer satisfaction and community relations through feedback mechanism. The various categories and sub-categories for these indicators have been listed in Table 3.

Table 3 Category, sub-category and indicators for Social Sustainability

Category	Sub-category	Indicator	References
Health and safety	Employee	Job availability and security	(Chaim *et al.*, 2018)
		Employee turnover rate	(Chaim *et al.*, 2018)
		Employee performance	(Holm, 2018)
		Legal benefits	(Lami & Mecca, 2021)
		Equality policy	(Cor *et al.*, 2014)
		Training and development	(Holm, 2018)
		Occupational health management	(Moreira *et al.*, 2018)
		Career advancement	(Gebisa & Lemu, 2017)
		Risk prevention and management	(Badurdeen & Jawahir, 2017)
		Protective equipment	(Cor *et al.*, 2014)
		Absentee's rate	(Bracke *et al.*, 2017)
	Customer	Product information	(Badurdeen & Jawahir, 2017)
		Customer satisfaction	(Borchardt *et al.*, 2011)
		Product quality	(Chaim *et al.*, 2018)
		Public trust	(Gebisa & Lemu, 2017)
	Community	Demographic aspect	(Holm, 2018)
		Technology development	(Chaim *et al.*, 2018)
		Human rights protection	(Bracke *et al.*, 2017)
Stakeholder Engagement	Employee	Employee feedback	(Cor *et al.*, 2014)
	Customer	Customer feedback	(Gebisa & Lemu, 2017)
	Community	Community feedback	(Chaim *et al.*, 2018)

FUTURE GOALS FOR IMPLEMENTATION OF SUSTAINABLE MANUFACTURING METRICS

The manufacturing sustainability assessment requires a uniform and systematic inclusion of various aspects of sustainability metrics (Stevanovic, 2018). In order to improve the results and to fill the void, a standardized course plan should be implemented based upon the consensus of manufacturers, stakeholders, and policy-makers (Sala, 2020). Since, all indicators might not be equally relevant in all industries, more efficient metrics should be developed so as to define priorities and measure indicator weights in varying sectors. The route for sustainability can be achieved step by step by completing seven phases as shown in Figure 3.

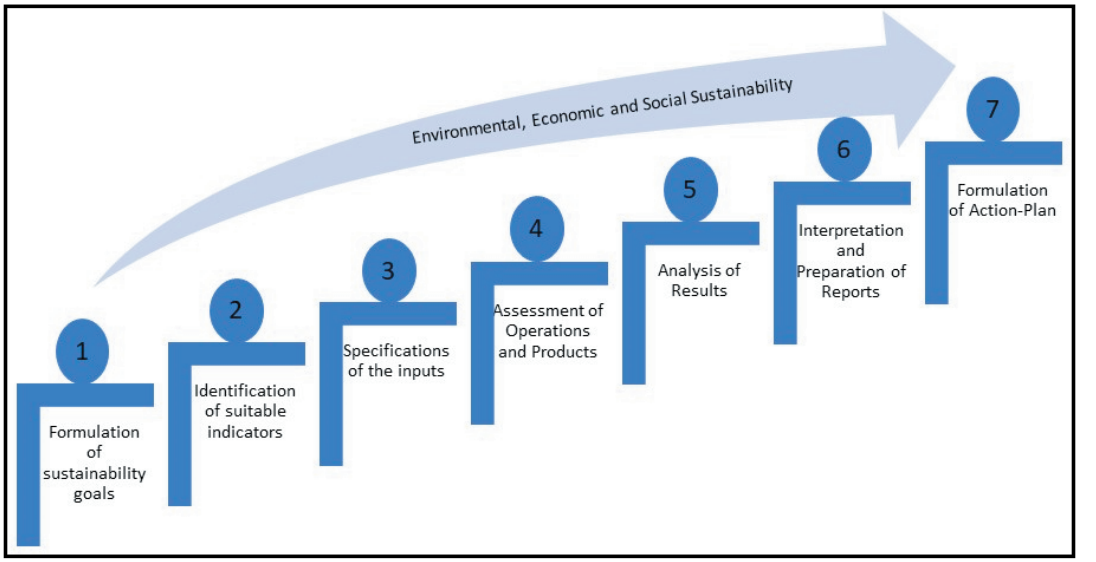

Figure 3. Route for Sustainability

The journey begins with formulating the sustainability goals as an addressal to various issues due to the environmental, economic, and social impacts of the manufacturing units through the involvement of management and stakeholders (Libório *et al.*, 2020). Depending upon the priorities, suitable indicators must be identified from the indicator repository that can suitably analyze the impact of various manufacturing operations and products through its complete life cycle. Various inputs like materials and energy resources used at all process levels must be specified and their impact on the environment, economy, and society must be identified (Taddese *et al.*, 2020). The efficacy and impact of all manufacturing operations on the environment, economy, and society must be assessed. The life cycle evaluation of the product must be carried out to determine its sustainability. The proper documentation of results must be carried out that can provide the contextual interpretation and indicate the performance trends of the manufacturing unit (Lami & Mecca, 2021). As per the final report, a necessary action-pan must be formulated for improved efficacy of the economy, environmental conformance, and healthy society in a steady and progressive manner by assigning new benchmarks and considering alternative options at each step (Rai *et al.*, 2021).

CONCLUSION

This paper addresses the basics, methods of implementation, and assessment tools for sustainable manufacturing using suitable sustainability indicators. The review and evaluation of various reports reveal that the three main sustainability assessment indicators don't carry equal weightage and less stress is laid on social indicators. Further, all

indicators are not used equally by various industries. In the case of environmental indicators, generally, more stress is laid on gaseous emission as compared to solid and liquid waste, possibly due to global consideration of air pollutants. However, industrial effluent is a prime matter of concern for food processing industries. Likewise, in the case of economic indicators, more frequency has been observed for revenue, investment, and operating cost as compared to taxes, wages distribution, and local economy. While, in the case of social indicators, more stress is laid on job availability as compared to equity policy and feedback. It is clear from this analysis that there are many deficiencies in measuring and managing sustainability in manufacturing units related to the sustainability market positioning. Hence, inclusion of all critical indicators can help manufacturers, customers, and policy-makers to address the environmental, economic, and social issues and lead towards sustainability in a steady manner.

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