A Novel Sustainability Assessment Approach in Manufacturing and Stakeholders' Role

Aamir Rasheed

Engineering Doctorate (EngD) Thesis

Supervisor: Prof Bill Ion

Department of Design, Manufacture & Engineering

Management

University of Strathclyde, Glasgow, UK

Published: 2022

Signed:  Date: 11th Jan 2022

Acknowledgements

I want to thank all those who helped and motivated me during my academic journey, whether related to industrial work, data collection, feedback from industrial and academic experts, or writing-up. This was not easy to manage with the support of my supervisors, work colleagues and people who participated in the appraisal and validation of the approach.

I would especially like to thank my supervisors, Prof Bill Ion and Dr Athanasios Rentizelas; without their feedback, support, and challenging questions, I would never have completed the work. I am also thankful to my colleagues and researchers at the Leonardo Studio in the DMEM department at the University of Strathclyde, Glasgow; they participated in my work at different stages and helped develop my proposed sustainability assessment approach to manufacturing. A special thanks go to Dr Dorothy Evans and Dr Abdul Ahmad, who gave me the energy and motivation to finish the work.

I am deeply grateful to Euan Morrison and Shona McMonagle, who helped form sustainability teams and validated and appraised the 3SM (sustainability score system in manufacturing) approach. I also appreciate the various industrial partners and stakeholders at my last place of work, who helped with data collection, sustainability approach evaluation, appraisal and validation, and constructive feedback to improve the approach at different stages. I am thankful to my family members: my beloved grandmother, my parents, my wife Mehak, my daughter Ayana and my son Musa.

All these people directly or indirectly influenced my work, and I appreciate them all. Finally, I would like to say thank you to Prof Bill Ion for his tremendous support in helping me complete my research.

ABSTRACT

With increasing consumer awareness about sustainability and governmental policies to address environmental challenges and social responsibility, the manufacturing sector is under continuous pressure to adopt more sustainable practices. There is a growing realisation that the manufacturing sector should adopt a proactive approach toward sustainability assessment, appreciate local and global sustainability trends, and incorporate stakeholders' sustainability concerns in manufacturing practices. Trends show that Factories of the Future (FOF) will need to adapt to market demands, growing economic and ecological efficiency requirements, and corporate social responsibility; such versatility is vital to address consumer disquiet and sustainability expectations.

There have been various approaches proposed to assess sustainability over the last few decades. Most of these approaches have limitations in that they are of marginal relevance to the manufacturing environment, tend to focus on only one aspect of sustainability, or are too complicated for most organisations to implement. Moreover, numerous studies have shown a gap in sustainability expectations among various stakeholders, and no active mechanisms exist to prioritise sustainability in manufacturing.

This research introduced a novel approach to addressing the manufacturer and multiple stakeholders' expectations about sustainability prioritisations in manufacturing practices. It achieved this using a modified Quality Function Deployment (QFD) tool and AHP and normalisation techniques. QFD has been used across the manufacturing sector to prioritise stakeholders' preferences and build them into the desired products or services. However, this research demonstrated a novel way of how QFD based approach can be used for sustainability assessment purposes. A set of system boundaries was adopted to evaluate sustainability in the manufacturing context; this research was a 'Gate to Gate' border.

The proposed assessment approach will help manufacturers better understand the link between the sustainability dimensions, multiple stakeholders' expectations involved directly or indirectly in manufacturing and account for their influence, and manufacturing functions, as well as assisting in setting performance targets that more fully consider both legal aspects and sector and organisational requirements. These indicators and a score-based approach will help organisations better grasp how manufacturing operations interact with sustainability and decision-making. They will help improve the allocation of corporate resources used to manage and improve sustainability performance in manufacturing.

Contents

List of Tables

List of Figures

LIST OF ABBREVIATIONS

3Ps	People, Planet, Profit
3Rs	Reduce, Reuse, Recycle
3SM	Sustainability Score System in Manufacturing
6Rs	Reduce, Reuse, Recycle, Redesign, Remanufacture, Recover
BOM	Bill of Materials
C2C	Cradle-to-Cradle
CO2	Carbon Dioxide
CSR	Corporate Social Responsibility
EPD	Existing Product Development
ESI	External Stakeholder's Impact
EN	Environmental Sustainability Indicators
EX	External Stakeholders Expectations (average)
FOF	Factories of the Future
HVAC	Heating, Ventilation and Air Conditioning
IP	Integrated Performance
ISI	InternStakeholders'ers Impact
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSP	Lowell Sustainability for Sustainable Manufacturing
MF	Manufacturing Functions
NPD	New Product Development
NIST	National Institute of Standards and Technology
OECD	Organisation for Economic Co-operation and Economic Development
PF	Performance Management

QFD	Quality Function Deployment
RD	Research & Development
RW	Relative Weight in Manufacturing
SAM	Sustainability Assessment Model
SI	Stakeholders Impact
SI %	Stakeholders Impact by percentage
SE	Sustainability Elements
STE	Stakeholders Expectations
SLCA	Sustainability Life Cycle Assessment
AHP	Analytical Hierarchy Process

Chapter 1 Introduction to sustainability

1.1 Background

According to scientists, life on Earth consists of a natural process about 3,900 million years ago. It started when the Earth had suitable conditions like moderate temperature, water, oxygen, and a favourable atmosphere (Joseph A., 1991; Mann, 2014). Life continued to evolve depending on good conditions on Earth. However, we are now facing numerous challenges, which include feeding the world's growing population, the depletion of non-renewable materials, biodiversity and also the environment, which is under threat from so much human activity (Bardi et al., 2016; Springer et al., 2016a; Vitousek et al., 1997). With this increase in the human population, carbon emissions, industrial waste, and the demand for more materials, a quarter of Earth's species are under threat of existence (Springer et al., 2016b; Vitousek et al., 1997).

Another major cause of climate change is a dramatic increase in industrial materials production and consumption. The continuously increasing needs of the growing population are challenging the Earth's ability to sustain life (Melkonyan et al., 2017; Pradella & Marois, 2015). Below is a table showing the consumption and utilisation of the Earth's energy and natural resources pattern over four decades. It indicated the growing energy demand, resulting in further utilisation of non-renewable resources.

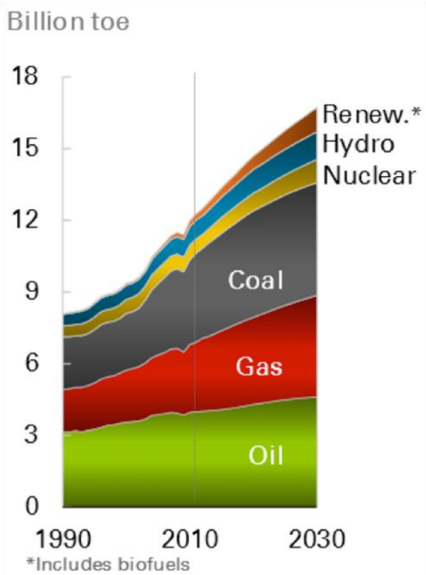

Figure 1-1 Energy consumption forecast by British Petroleum (BP, 2013)

A tremendous amount of fuel is burnt worldwide in industry and automobiles daily. This phenomenon, combined with a dramatic increase in population, is pressurising not only the limits of planet Earth but is also responsible for many undesired and alarming situations affecting human life. Although some estimations indicate that we have already reached the natural fossil fuel consumption peak, fossil fuels are predicted to last for only the next 40 to 50 years (Davig et al., 2014). This means fossil fuels could end up short due to the shift to alternatives such as renewables.

Overpopulation occurs when the number of human beings in a specific geographical location exceeds that environment's ecological capacity. It can result from various factors, including an increased fertility rate, a decline in mortality rate, or increased immigration. There are too many people in a given habitat resulting in the depletion of available resources, and the environment loses its capacity to sustain life in that specific habitat (Tamburino et al., 2020).

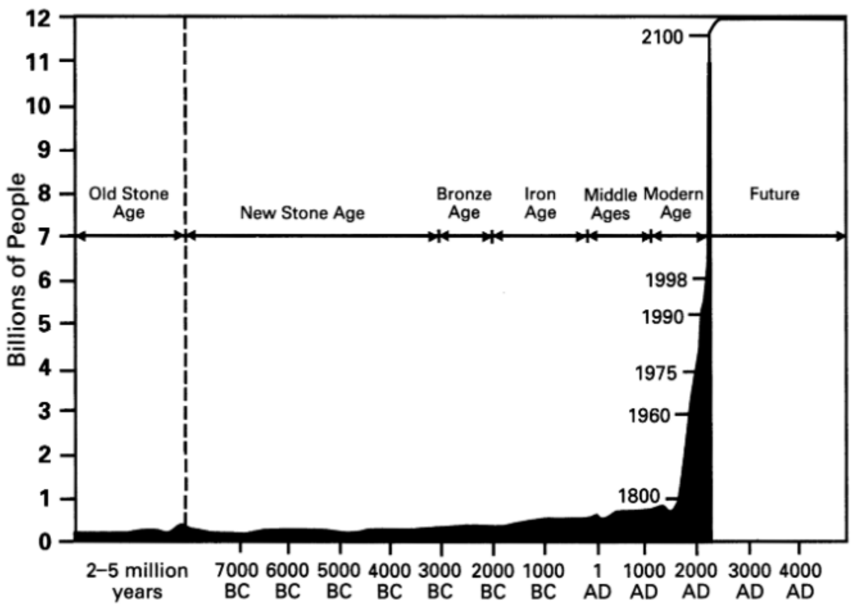

Figure 1-2 Human population in history and future context (Exposing Game, 2015; Joseph A., 1991)

Figure 1-2 shows that the world population throughout history was almost constant over the last 10,000 years until the modern age and dramatically increased over the previous three centuries. This increase over such a short time was due to industrial, technological, agricultural, and biological advancements resulting in more access to food, medicine, and greater access to Earth's materials. The quality of life improved over this period but at a higher environmental cost.

Our changing lifestyle is crucial in the increasing need for material production. According to some theories, the number of consumers in the global supply chain will double by 2025, making manufacturers' environmental sustainability a significant challenge (Swartz, 2016). It has been estimated that in the next 5 to 10 years, there will be approximately 1.8 billion new customers classed as global consumers (Swartz, 2016). This recent phenomenon will pressure manufacturing and policymakers to understand and address the growing demands and new challenges (Swartz, 2016). These factors and the desire for a better lifestyle have consumed more materials to meet growing human needs and demands.

According to various studies, it has become clear that the Earth already has reached a point where current production and consumption practices cannot be sustained over the next century (Despeisse, 2015; Hay, 2015; Swartz, 2016). Our planet does not have enough resources for future generations, and we need to change our living standards and practices to meet the increasing demands of the human population (Swartz, 2016). Furthermore, a higher search for more renewable energy resources and subsequent adoption is required to survive and live better.

The scale of the problems outlined above means we must shift to sustainable production and change in lifestyle. To summarise, the need for sustainability in manufacturing arises mainly from the following areas:

- Changing lifestyle on the planet
- Growing energy requirements of the manufacturing sector
- Increasing awareness among multiple stakeholders about the environment and sustainability
- Pressure from legislative bodies to address sustainability issues and adopt best practices

Sustainable manufacturing is an approach that develops methods and procedures to reduce manufacturing's environmental impact. This also offers improved energy and resource efficiency, generates a minimum quantity of waste, enhances people's health by improving operational safety, and improves product and process quality with overall life cycle cost benefits. Sustainable manufacturing is the way to make this planet habitable for all species, including humans. It depends upon sustainable processes, materials, and the supply chain. Sustainable manufacturing is a comprehensive approach that will overcome the traditional 'lean and green' manufacturing approaches (Faulkner & Badurdeen, 2014) and utilise comprehensive techniques to maximise the utilisation of resources, which means more financial, social and environmental benefit

Figure 1-3 Evolution of manufacturing strategies adopted (Faulkner & Badurdeen, 2014)

Evolution of manufacturing strategies showing benefits in Figure 1-3 of exponential increase in the stakeholder's value achieved by managing embodied energy and material flow in a closed-loop lifecycle. It shows how manufacturing techniques have evolved from traditional to sustainable and improved stakeholder value. Traditional manufacturing strategies depend upon the pre-manufacturing, manufacturing, and use stages of product lifecycles, resulting in excessive resources. This waste is reduced in lean manufacturing techniques since it focuses primarily on waste elimination (Reduce). Green manufacturing strategies use the 3Rs: reduce, reuse and recycle. However, neither of the processes mentioned above make use of end-of-life products. Sustainable manufacturing is a closed-loop process enabling the total lifecycle-based material flow. It reduces the materials used and energy consumed and recycles materials where possible. It then recovers materials where possible and redesigns them in a remanufacturing process; this differs from traditional manufacturing. Sustainable manufacturing results in materials and energy gains and maximises asset usage for the manufacturer. It enables us to benefit from these products as well as making use of not just 3Rs, 6Rs and now enhanced to 7Rs:

- Reduce
- Reuse
- Recycle
- Recover

- Redesign
- Remanufacture
- Repurpose

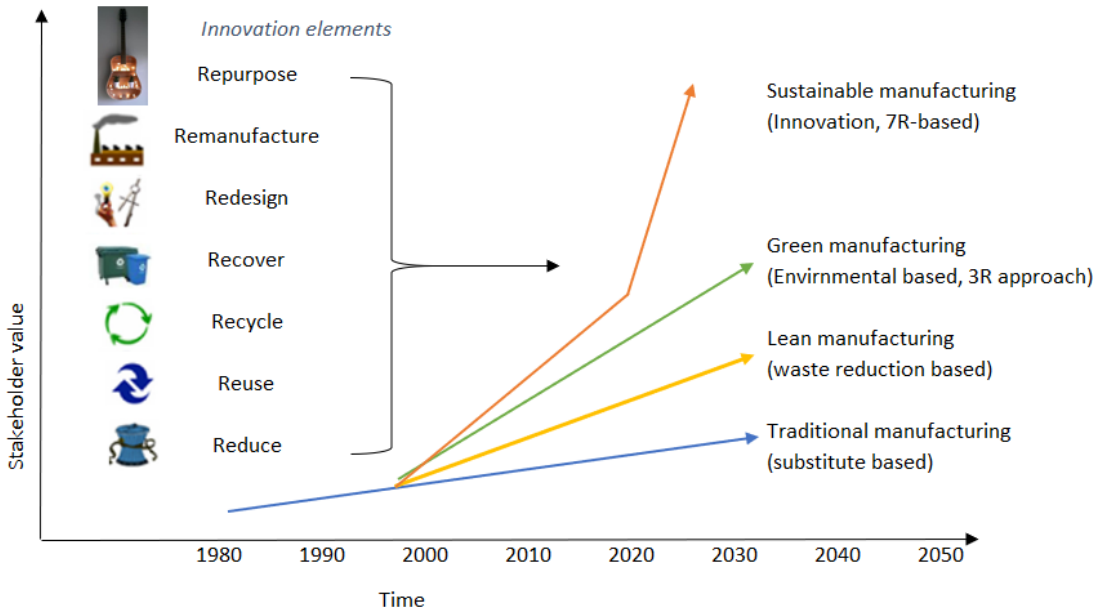

Figure 1-4 Evolution of manufacturing strategies highlighted by (Brissaud & Zwolinski, 2017; Faulkner & Badurdeen, 2014)

Figure 1-4 shows the superiority of sustainable manufacturing over lean, green and traditional manufacturing techniques due to its innovative 7Rs approach. The vertical axis in Figure 1-4 shows the stakeholder increment in stakeholder value using different strategies. The most valuable addition to stakeholders' interest is repurposing components, which means the features, after completing their life and purpose, can transform and manufacture for different products and purposes (Brissaud & Zwolinski, 2017). The 7Rs approach is more comprehensive and high value than the 3Rs traditional green manufacturing approach, which is restricted to reducing, reusing, and recycling (Faulkner & Badurdeen, 2014).

The 7R's comprise reducing, reusing, recycling, recovering, redesigning, remanufacturing, and repurposing components. Sustainable manufacturing derives from reducing the consumption of materials and resources where possible. Once the materials are investigated, some can reuse the same or alternative processes to maximise resource utilisation. Then the next stakeholder value derives from recycling materials, recovering where possible, and investigating the redesign opportunities where it attracts different stakeholder value and additive value in manufacturing.

Remanufacturing saves up to 85% of energy through life and materials than conventional manufacturing, so there are many opportunities in this domain (Bernard, 2011; Paterson et al., 2017). Remanufacturing and repurpose techniques are superior to sustainable manufacturing techniques where maximum value may recover (Brissaud & Zwolinski, 2017; Faulkner & Badurdeen, 2014). It also shows a trend predicting that sustainable manufacturing will eventually become the dominant approach in years since it is a comprehensive approach that accounts for all aspects of manufacturing and society.

The 7Rs approach comprises:

- Maximising the use of available resources and adopting best practices.
- Technique focus on minimising energy & materials consumption (keeping the minimal burden on the environment and nature).

Companies that comprehend the importance of sustainable manufacturing are already using these resource-efficient techniques. Sustainable manufacturing is not limited to operational efficiency — something critical in all other production types — it also provides a complete philosophy for business and covers environmental issues. Sustainable manufacturing addresses ecological challenges, social development, and the organisation's financial stability and future viability.

In sustainability, one should create "plans and activities that make an optimal contribution to sustainable development" (Verheem & Laeven, 2009). Exploring the methods currently used in sustainability evaluation and assessment frameworks is essential to understand their limitations and benefits.

1.2 Research background and area of interest

In 1987 the United Nation's Brundtland Commission produced a comprehensive report on its findings regarding sustainable development, social responsibility, and the planet's protection. It was known as 'Our-Common-Future' (Brundtland, 1987) when the commission provided the first comprehensive report about production and consumption patterns in industries and the social system attached to sustainable development. Sustainable development has an active link with the environment and the social network; Industrial development impacts and role in sustainable development. Therefore, sustaining and controlling industrial growth is vital

(UNIDO, 2014). The role and concept of multiple stakeholders in sustainability assessment (Fobbe & Hilletofth, 2021; Tuni & Rentizelas, 2018) are demanded to improve performance in the supply chain.

The manufacturing sector is under increasing pressure to deliver continuous growth amid changing legislation and social pressure to protect the environment. Trends show that Factories of the Future (FOF) must adapt according to the evolving market trends and consumers' expectations and consider the growing requirements of ecological economies and materials conservation (Swartz, 2016). On the other side, the manufacturing sector is also facing further pressure from governments and consumers to improve sustainability in manufacturing in the form of targets to reduce carbon emissions, placing a more significant financial burden on them. Government bodies are also setting limits to protect nature and society from industrialisation. Sustainable manufacturing focuses on developing business models and practices with competitive returns on investment, minimal environmental impact and a positive contribution to society (Al-alwani, 2014).

Sustainable manufacturing and development are vital in maintaining a better lifestyle and world prosperity, sensibly utilising Earth's available resources (Joung et al., 2013a). It is essential to set sustainable manufacturing goals, which should be monitored regularly (Beerling & Berner, 2005). An improved sustainability assessment methodology can help decision-makers and policymakers determine actions to take to improve sustainable manufacturing and society's prosperity (Devuyst, 2001). Defining and assessing sustainability is vital for tracking performance and setting critical goals (Veleva et al., 2001). Sustainability has different dimensions, i.e. addressing environmental challenges, economic growth, social aspects, best practices in manufacturing, and performance management (Mani et al., 2013; NIST, 2015).

Sustainability sits firmly on the agenda of manufacturing companies, and trends show that in the coming years, consumer interest and loyalty will be higher for those companies which manage sustainability issues well (Delloitte 2020, n.d.; GRI, 2018). The impact of stakeholders on corporate sustainability performance keeps increasing, and new government taxation and legislation in the manufacturing sector reflects this (Amini & Bienstock, 2014). Numerous studies have shown that companies ignoring sustainability issues and stakeholders' concerns in manufacturing will distance themselves from consumers (Defra, 2007; Deloitte, 2012). Sustainability performance indexes are among the most common assessment criteria globally and locally (Mascarenhas et al., 2010; Stork et al., 1997; Veleva et al., 2001).

There are several definitions of sustainable manufacturing, and most of them highlight and relate to the environment, social responsibility, and economic elements. It is essential to set a framework that helps select manufacturing methods and addresses stakeholders' sustainability assessment concerns. Such a scheme will allow manufacturing companies to understand sustainability and re-address the issue in the supply chain. According to (Despeisse, 2015), sustainable manufacturing maximises natural resources such as light and temperature. It also uses technology to improve employees' lives by promoting health and safety conditions, reducing physical fatigue, and introducing energy-saving initiatives to enhance organisational performance.

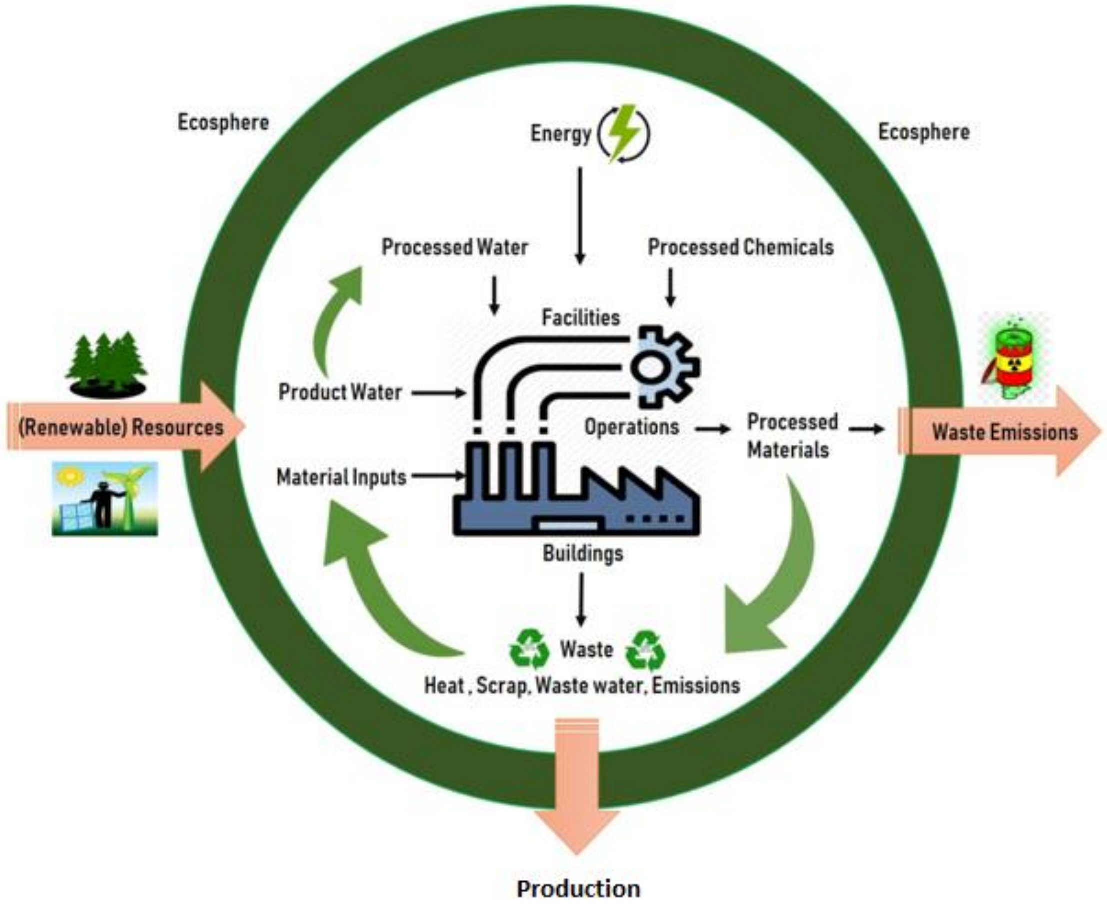

Figure 1-5 Manufacturing (eco) system model with the sub-systems and resource flows, adopted from (M. Despeisse, 2012)

The model shown in Figure 1-5 highlights three main components of manufacturing systems to improve sustainability in manufacturing. It indicates that when goods are produced with input materials, some undesirable outputs such as emissions and waste and managing unwanted production and keeping them within consent are part of sustainable manufacturing.

- Manufacturing operations.
- Supporting facilities.
- Surrounding buildings.

These components linked resource flow materials, energy, and waste within system boundaries. Manufacturing facilities, buildings, and operations convert raw materials into valuable objects. According to Despeisse (2015), for manufacturing to be sustainable, it needs to maximise its renewable resources and assets. The model shows that inputs materials and renewable resources are consumed to generate desired products, and undesired outputs are generated. The focus should be on maximising resource utilisation at improved performance to maximum utilisation and results. Sustainable manufacturing is based on sustainable products and processes across the supply chain (Carnevalli & Miguel, 2008; Faulkner & Badurdeen, 2014). The operations and processes in manufacturing facilities and buildings generate unwanted waste (including solid waste) and emissions into the environment — this affects the Earth's equilibrium and needs to be managed responsibly. A precise sustainability assessment considering all manufacturing aspects, including emissions, effluent, and undesirable outputs and limits, will increase manufacturing confidence among multiple stakeholders.

1.3 The concept of sustainability

Sustainability concept depicts the meaning of the upholding status or condition, considering the environment with sustainability concept meaning the changes of resources, the direction of improvements, the orientation of technological development, and institutional change are all in synchronisation and enhance both current and future potential to meet human needs and aspirations (Defra, 2013; Faulkner & Badurdeen, 2014; Swartz, 2016). Several sustainability methods, approaches, and models were examined to identify the best fit for a sustainable manufacturing approach.

Traditionally, sustainability is based on three essential aspects: environmental, economic, and social. For this research, these were termed sustainability dimensions or pillars. The concept is studied in many fields, such as environmental sciences, particularly business and management. The environmental factor is one of the elements in the supply chain. It is essential in determining its impact on firms and its bearing on supply chain operations (Goodland & Bank, 1995). These societal forces are concerned with sustainability performance which protects the environment and biodiversity and creates a better workplace and social life for employees and people involved in the supply chain. However, firms are typically more interested in profit and focus on the business's economic performance. Stakeholders' and society's expectations are often absent in organisation sustainability actions (DEFRA, 2006).

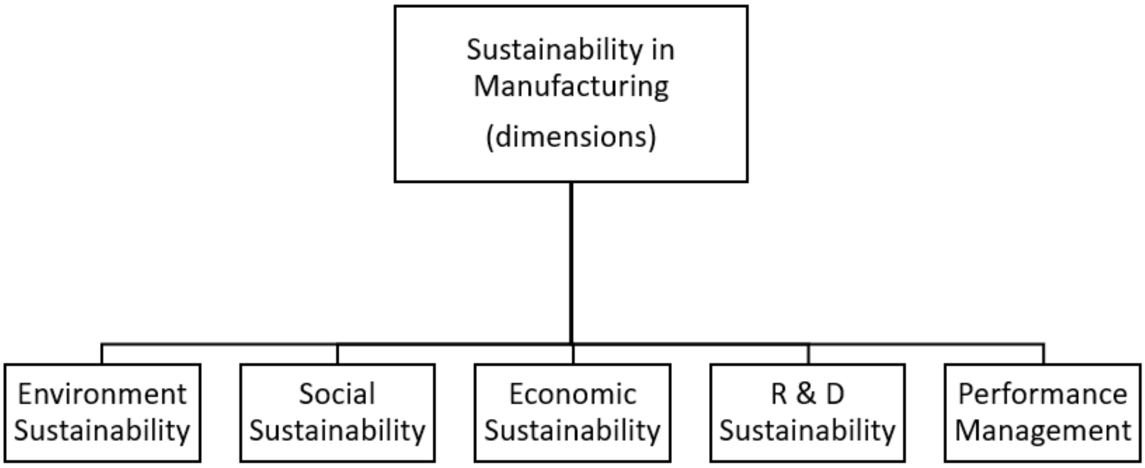

Figure 1-6 Shows the five sustainability dimensions for sustainable manufacturing (NIST, 2015)

According to the US National Institute of Standards and Technologies (NIST, 2015). In the manufacturing context, there are five critical aspects of sustainability, i.e. sustainability dimensions, as shown in Figures 1-6. A comparative study of different sustainability approaches found that most were environment-focused and did not address the other critical aspects of sustainability such as social, research & development and performance management. The literature review (Chap 2) and analysis of different sustainability assessment approaches (Table 2-6) in the manufacturing context provide the absence of multiple stakeholders' input. This leads to a split and broader gap between manufacturers' efforts and stakeholders and customers' expectations about manufacturing (Jayal et al., 2010). With the increasing awareness of consumers about sustainability elements, the customer's requirements keep changing, and an active mechanism should place to access the change in demand (Horan, 2022).

The most common guidelines for evaluating sustainability in the industry are with Global Reporting Initiative (GRI) 4.0, which over twelve thousand organisations adopted to assess and report sustainability performance (GRI, 2018). However, it does not consider relevant stakeholders' expectations and the manufacturing dynamics of organisations. This gap exists in most sustainability approaches, not just ones about manufacturing.

Researchers and experts agree that sustainability, including production and people's consumption patterns, is crucial for securing a prosperous future. Various approaches are practised and published in academic literature, but most are generic or applied to specific scenarios. What is needed is a flexible approach that can be customised to meet any organisation's needs in the manufacturing sector. Manufacturing organisations must better measure, monitor, control and deliver sustainable manufacturing technologies. Organisations must analyse feedback from stakeholders, meet consumer demands, and cope with the changing trends in modern industry.

1.3.1 Research motivation

Sustainability assessment has gained much attention from researchers and practitioners over the last two decades. Companies have shifted the focus toward sustainability to such an extent that they consider it the need of the hour. As a result, sustainability issues are becoming an essential part of marketing strategies. Sustainable marketing helps build and maintain longer-lasting associations with business stakeholders and consumers.

It is worth considering why companies are now championing sustainable manufacturing and sustainability marketing. Recent research shows that stakeholders — including consumers — persuaded organisations to incorporate sustainability into their business practices (Swartz, 2016). Stakeholders are now critical influencers in a company's agenda regarding sustainability practices. Most researchers have tried to study stakeholders' role in traditional and green manufacturing; none has discussed this issue concerning sustainable manufacturing, so there is a need to conduct studies with a broader standpoint on sustainability (Fobbe & Hilletofth, 2021; Malamud, 2015; Muwazir Mukhazir, 2011).

Most manufacturing organisations select a sustainability model with some relevancy and sector acceptability but overlook manufacturing operations, the stakeholders' expectations, and their role in prioritising sustainability preferences (Yazdani et al., 2016). However, internal and external stakeholders are crucial. Since internal stakeholders know operational manufacturing, they understand its core issues and sustainability. The combined knowledge of internal and external stakeholders can provide meaningful information for decision-makers and manufacturers to act upon and meet market expectations. It became apparent through 17 years of industrial experience in the Food and drink sector while managing sustainability, working closely with those in the manufacturing sector, and through a structured literature review that there is an urgent need for a customised sustainability assessment approach which:

- Quickly identifies manufacturing dynamics within a given company.
- Address multiple stakeholders' expectations and influence in the organisation.
- Develops a sustainability assessment model that includes local and international sustainability trends and industry requirements.

It provides the impetus for developing an improved, flexible sustainability model, validated through each stage, suitable for the manufacturing sector, and considers stakeholders and markets' expectations.

After the structured literature review and a review of the existing sustainability assessment tools, a more accurate and comprehensive method to assess sustainability for manufacturing companies addresses existing gaps in current practices, this work included internal and external stakeholders' requirements, sector preferences, and understanding of local and international laws in the manufacturing and sustainability domain.

1.3.2 Scope of research

A persistent challenge in managing sustainability practices is understanding the importance of stakeholders' concerns. Therefore, manufacturing firms must pay close attention to sustainability performance assessment. Sustainable manufacturing is a rapidly growing area that warrants further exploration. The findings of this study will provide a deeper understanding of sustainable development in industry, making more efficient use of resources while simultaneously maximising profits. It will also give an insight into the role of stakeholders in sustainability performance assessment. Such an understanding will help managers, academics, and marketing experts analyse and understand the importance of manufacturing sustainability.

Manufacturers, customers, and stakeholders play an equally important role in developing environmentally friendly, sustainable manufacturing approaches (L.-A. Ho, 2011; W. Ho et al., 2011; Swartz, 2016). Multiple stakeholders, including the manufacturer, have their interests and expectations. A wide gap exists between manufacturers, consumers, and stakeholders regarding sustainability prioritisation (Jayal et al., 2010). This gap needs to close by discussing sustainability performance assessment in the industry and stakeholders' role in achieving the goals desired by manufacturers. Stakeholder pressure can, in turn, enable firms to adopt sustainable supply-chain practices essential for achieving sustainable performance. They can accomplish this by considering product and process-design activities.

In this research, sustainability assessment in manufacturing is a focal issue as a substantial amount of materials and resources are used to produce valuable goods in factories. Due to increasing consumer awareness and tightening legislation for reducing carbon emissions, manufacturers and consumers are now prioritising the sustainability performance assessment of systems, products, processes, and manufacturing operations. To improve sustainability performance in manufacturing is essential to select relevant indicators, track the values, and record and analyse them to find opportunities and methods for improving performance. Various efforts have been made in this area, but none have considered customising manufacturing operations and meeting stakeholders' demands. The research will provide greater insight regarding present problems in this field and help researchers explore the area further. It provides industry-related information, especially the analysis of the role of stakeholders in sustainable manufacturing. This study proposes a 'sustainability assessment approach' design and discusses methods adopted to achieve the research has desired aims and goals are supported through literature and industry practices (Vinodh et al., 2017; Yazdani et al., 2016)

1.3.3 Multiple stakeholders

Multiple stakeholders are vital parties interested in and influencing the organisation. The organisation's objective is to create as much value as possible for the stakeholders and ensure that its strategies and actions are coordinated to address their expectations. To better understand stakeholders' roles, it is essential to identify those stakeholders and the nature of their expectations first.

Table 1-1 Stakeholders and their objectives (Plaza, 2015)

Stakeholder	Objectives / Expectations
Management	Authority, corporate culture, strategies, and overall performance
Shareholders	Profit and the value of the stock in the stock market
Customers / Consumers	Features of the product and quality of services
Government	Security of society, dominion, respect for the laws, and payment of taxes
Community	Environmental and social effects
Employees	Fairly salaried employment, working conditions, and job satisfaction
Suppliers	Price and volume of procurement and sustainability
Banks	Payment systems and their flexibility
Investors	Information about the liquidity and viability of payment

Organisations use their efforts to address and design manufacturing or services to satisfy stakeholders' expectations and influence manufacturing and sustainability prioritisations. Multiple stakeholders in manufacturing organisations may extend to the following parties and are not limited to those discussed in Table 1-1

- Those who use organisation products or services directly
- Those who use competitors' services or products
- Those who are satisfied with the products or services
- Those who are dissatisfied
- Those who can or may influence the organisation's business
- Those partners directly or indirectly add value to the business
- The manufacturing sector, including market forces
- Internal stakeholders and business influencers
- National and international legal and governing bodies

Therefore, it is vital to understand and involve all key stakeholders while developing a sustainability assessment approach (Plaza, 2015; Swartz, 2016).

1.3.4 Justification of research

Sustainability assessment is an approach that assesses sustainability performance in manufacturing, the supply chain, or in a context within any given predefined system boundaries. It serves as a guide for decision-makers to enhance sustainability performance. Due to increasing environmental problems and massive social disparities in global development, modern civilisation has assumed that sustainable manufacturing is the foremost developmental model. Despite various governmental promises and the admiration of sustainable manufacturing as part of sustainable development among several stakeholders, its applied operation falls short. Sustainable manufacturing must be viewed as a decision-making approach when discussing the gap between words and actions since decisions influence every step. Sustainability assessment helps in decision-making and can significantly improve the understanding of manufacturing sustainability by addressing three challenges: experience, information-structuring, and effect.

- **Understanding:** Sustainability should be understood by observing its ability to establish values useful in a given socio-environmental situation.
- **Information-structuring:** The characteristic multi-dimensional intricacy of sustainability should be organised into operational information units and connected correctly to feed the decision-making process.
- **Effect:** Sustainability information should wield a real impact on decision-making and the actual application of sustainable development.

A comprehensive approach with an elevated organisational commitment is required for sustainability and sustainable manufacturing (Fan et al., 2010). Some characteristics and conditions of sustainability include environmental stewardship, economic growth, social aspects, and research and development initiatives to address sustainable manufacturing commitments (NIST, 2015). These main characteristics and sustainability features can support, evaluate, report, and, most importantly, the decision-making process (Stork et al., 1997; Veleva et al., 2001). However, various studies point to the split between the manufacturers' and stakeholders' expectations about the sustainability prioritisations (Jayal et al., 2010; Swartz, 2016); there still exists a wide fissure between manufacturers' and consumers' expectations of the sustainability elements preferences.

Table 1-2 Weight assigned to sustainability elements by manufacturers and consumers (Jayal et al., 2010)

Sustainability elements	OEM (%)	Consumer (%)
Environment Impact	30.5	18.3
Societal Impact	8.0	22.9
Functionality	31.5	22.3
Resource Utilisation/economy	10.0	20.2
Manufacturability	10.5	N/A
Reachability /remanufacturing	9.5	16.3

Table 1-2 shows the split of the manufacturer and consumer prioritisation of sustainability elements. A gap exists between manufacturing efforts and what consumer wants. This demands accurate sustainability assessment in the manufacturing sector and addresses stakeholders' involvement (Defra, 2006; Deloitte, 2012; GRI, 2014). Sustainability assessment in manufacturing provides the understanding of operations and opportunities and thus helps in the decision-making process for the best allocation of manufacturer efforts (Hay, 2015; Stork et al., 1997).

1.4 Chapter summary

This chapter introduced and discussed the definition, concept, importance, and background of sustainability. Sustainable development plays a crucial role in maintaining a balanced system on the planet, including population growth, technological development, and how humanity uses the resources available. The first part of the chapter was about the drastic changes in our planets, such as global warming, rapid environmental changes, and biodiversity decline. Secondly, this research's context, motivation, and scope were discussed. Thirdly, sustainability assessment was discussed in detail, emphasising the characteristics of an ideal approach that better incorporates stakeholders' expectations. The research aims, its contribution to the field, and the work's novelty were presented.

Figure 1-7 Thesis structure and research process

What does reader want to know?	Why it was relevant?	What does the chapter discuss?
Chap 1: Introduction What is research about?	Introduce the research, its context and importance. Overview of the work presented in the thesis. Sustainable manufacturing, stakeholder's role in sustainability assessment.	Research background and topic. Research aim & objectives. Research questions:
Chap 2: Literature review What is already known, practice and gaps?	Analysis the current assessment practices about sustainability, investigation of gaps and stakeholder's role in manufacturing.	Gaps in knowledge & practices through analysis of sustainability assessment approaches in practices. An alternative QFD approach in assessment. Stakeholders role in sustainability evaluation.
Chap 3: Research design What was research done?	Explained scientific rigour and understanding of research philosophy and design options.	Research process overview: purpose, methodology. Research philosophy adopted: post-positivism Research methods: Case study, pilot study, theory building and validation in similar environment.
Chap 4: Sustainability assessment approach How to develop an improved sustainability assessment approach specific to manufacturing and its justification?	Developed a customised sustainability assessment approach specific to manufacturing. Involvement of specific sustainability stakeholders is appreciation of relevant sustainability elements.	Sustainability model development and validation approach adopted in model. Explained stages involved in sustainability evaluation. Appraisal of sustainability model '3SM' by relevant experts.
Chap 5: Sustainability approach validation. How sustainability approach '3SM' relevant to manufacturing?	At this stage sustainability model '3SM' validated in manufacturing company by following steps recommended in sustainability evaluation approach. Used sustainability data and model appraised by sustainability practitioners and company management.	Using sustainability assessment approach outlined, setup sustainability team, consulted management, select sustainability boundaries, prioritise sustainability elements, sustainability indicators, investigate hotspots in sustainability and in manufacturing, set sustainability short term and long-term targets and develop a sustainability score out 100 to help company management and decision makers sustainability.
Chap 6: Discussion and Conclusion. What are the findings? What are the implications? What are the next steps?	Explained how findings answered the research question and answered research objectives set in first chapter. Explained how sustainability approach is relevant to manufacturing and why need of customised sustainability assessment approach require in manufacturing.	Synthesis of research findings. Contribution and originality of work. Research limitations. Recommendations for future research and potential expansion of sustainability model in other sectors.

1.4.1 Publications from this work.

Conference paper

Rasheed, A., Rentizelas, A., & Ion, W. (2017). *Sustainability performance framework in manufacturing (SPFM)*. The Production and Operations Management Society (POMS) 2017 International Conference, Sydney, Australia.

Journal papers:

Rasheed, A & Ion, W 2022, 'A novel approach towards sustainability assessment in manufacturing and stakeholder's role', *Sustainability*, vol. 14, no. 6, 3221. https://doi.org/10.3390/su14063221

Chapter 2 Literature review

The planet recently entered what some scholars term the Anthropocene period. In this new epoch, human activities, such as excessive use of fossil fuels, land-use change, and industrialisation, are now the dominant influence on Earth, aggressively unsettling its delicate ecological equilibrium. Manufacturing plays a vital role in sustainability and significantly contributes to carbon emissions, resulting in global warming and climate change (EPA, 2014; Hauschild et al., 2005). The impact of greenhouse gases from industrial manufacturing is alarming; about 1/5 of total emissions come from industrial activities (Ingarao et al., 2011; William Colton, 2017). Manufacturers and consumers demand greater clarity about the role of manufacturing in sustainability performance, such as how it deals with sustainability pillars, particularly the environmental aspects, and how manufacturers should address concerns regarding sustainability in business.

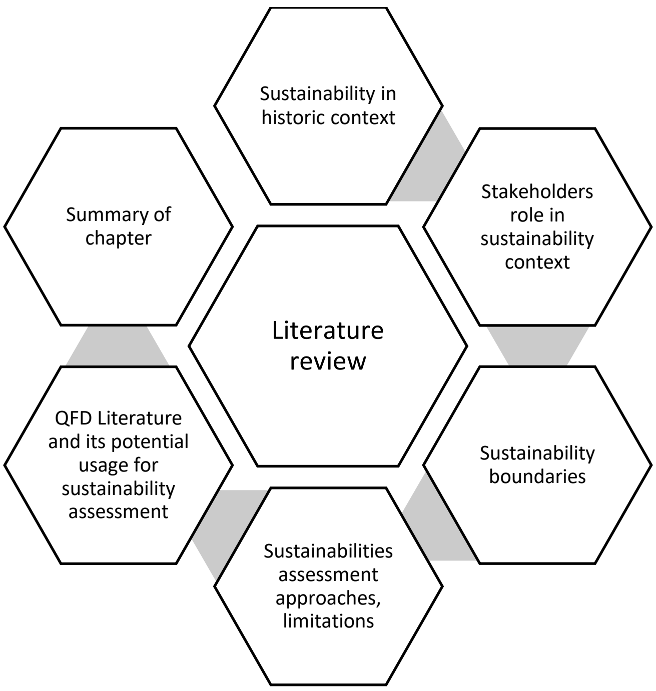

Figure 2-1 An overview of the literature review

This chapter discusses sustainability in manufacturing and sustainability assessment approaches, starting from a historical perspective and continuing with its definition, and how sustainability values have changed over time. The research review's starting point was to understand the topic by consulting scientific journals, books, relevant websites, reports and grey literature, and practical models used in the industry.

While conducting the literature review, words and phrases such as 'sustainable development, 'sustainability', 'sustainability issues', 'sustainable manufacturing', 'sustainable manufacturing indicators', and 'sustainability assessment practices' were entered into different academic search engines to find the latest and most relevant research on the topic between 2014 to 2020. Further refinement followed, addressing the research question, shortcomings in current sustainability approaches, the potential of the QFD tool in the sustainability domain, and the multiple stakeholders' role in sustainability assessment and management in the manufacturing sector.

2.1 Meanings of sustainability

The concept of sustainability is still only partially understood and accepted; some aspects remain a subject of debate. There are different assumptions and opinions regarding present sustainability levels on the planet among scientists and society. Some researchers and industry practitioners assume the Earth's carrying capacity may have already been exceeded, whereas some argue there is still a sufficient margin for a transition to sustainability. However, in all cases, it is agreed that change is needed. The manufacturing sector and consumers must address sustainability issues in their practices and change lifestyles (E.G., 2005; Fuss et al., 2014).

In the past, sustainability meant 'surviving under extraordinary and harsh conditions' (Ehrenfeld, 2005). However, sustainability has become more associated with environmental issues such as carbon footprints and biodiversity (Delai & Takahashi, 2011). The meanings trace back to the eighteenth century when the term "Nachhaltigkeitsprinzip" was first used in German forestry management; it pertains to maintaining sufficient wood in stock to meet steady demand and growth (Floyd et al., 1995; Hay, 2015). Terms such as 'sustainable development' and 'sustainability' began appearing in literature concerned with the environment in the 1970s and 1980s. The concept of sustainability has since evolved in many other areas (Kidd, 1992), and over the last couple of decades, it has become prominent in many sectors, especially manufacturing. The term can have different meanings in different business sectors, including manufacturing (Ehrenfeld, 2005; Floyd et al., 1995; Hay, 2015; Kidd, 1992). However, a broad consensus is that sustainability relates to business practices that do not compromise the environment and social phenomena.

2.1.1 Lexical definition

The term sustainability is derived from the Latin verb 'sostenere', which means 'to uphold' the status(Hay, 2015; Rametsteiner et al., 2011). In the notes of different researchers (Hay, 2015; Kajikawa, 2008), the literal sense of sustainability is the 'ability to sustain over time and maintain status over that period. In assessing most of the definitions discussed (Hay, 2015), 'sustainability', as identified in the literature, means the ability to sustain the situation and then maintain its status and continue rather than deteriorate with time.

This three-fold definition applies regardless of the context. In sustainability evaluation and search for an improved approach, the challenge is to examine current assessment practices and their relevance in manufacturing and discover the gaps between current assessment and the required performance criteria, improving the status or situation as described. Sustainable manufacturing stands on three pillars: economic, social, and environmental sustainability (H. Zhang & Haapala, 2015). Sustainability is maintained when all three pillars are upheld, i.e. each dimension of sustainability is preserved. No pillar should be prioritised at the expense of any other sustainability pillar (Muñoz-Torres et al., 2018; H. Zhang & Haapala, 2015). If one pillar is not upheld, then by definition, the manufacturing process cannot be deemed sustainable.

The most commonly accepted view on sustainable development comes from the Brundtland Commission. Its report shows how current needs can be met without compromising future generations' ability to meet theirs (Brundtland, 1987). The three sustainability pillars it lays out have been widely accepted. These are the so-called triple' bottom line' or '3P's' of people, planet, and profit (Elkington, 1997). The goal is to meet the societal wants of the existing population while at the same time conserving natural capital for future generations. Technology is typically considered a critical fourth pillar because it is the principal means the leading three pillars can be upheld and enable change (Jovane et al., 2009).

2.1.2 Types of sustainability

Sustainable manufacturing stands on three pillars or dimensions: economic, social, and environmental sustainability (H. Zhang & Haapala, 2015). Sustainability is satisfied when no sustainability pillar net value is negative is considered a case of strong sustainability. Sustainability may be further divided into strong and weak sustainability (Garmendia et al., 2010). These types are based on the argument of 'transferable sustainability pillars', and sustainability pillars can be summed as an example of weak sustainability; this means the negative environmental effect on the planet can be justified with social and economic gains (Coulson, 2014; Fallis, 2013; Harris, 2003).

2.1.2.1 Strong Sustainability

Strong sustainability exists where the total amount of materials or substances gradually increases, or there is no threat to the long-term availability of that material at the current rate of consumption in nature (Fallis, 2013; Harris, 2003) and means the same amount of virgin material consumed in the bank of natural assets.

Another definition of strong sustainability is that the three sustainability pillars are not transferable, meaning environmental loss cannot justify economic gains or social welfare (Baxter et al., 2003). Finite materials in nature, high usage of materials, and less conservation of them indicate a situation where we do not need enough materials for future use (Baxter et al., 2003).

2.1.2.2 Weak Sustainability

Weak sustainability stipulates that an economy is sustainable if its capacity to generate income for future generations, a capacity embodied in its capital stock, is maintained (Hartwick, 1991). Weak sustainability occurs when indicators show that the net asset of substances or materials declines faster. It indicates that the exact quantity will not be available in the future; not enough is being kept or replaced in 'nature's bank'. It leads to weak sustainability, whereby some substances may not exist in the future and cannot replenish. Most metals and fossil fuels are non-renewable and finite in quantity, so if they are not conserved or do not recover, we may end up with less of them, or none of them, in the future (Evans et al., 2005; Hartwick, 1991).

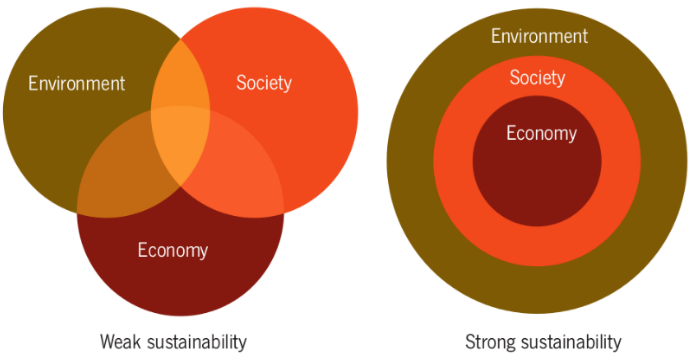

Figure 2-2 Sustainability pillars in the form of weak and strong (Amitrano, 2016)

The concept of weak and strong sustainability merges environmental, economic, and societal growth — as shown in
Figure 2-2. The weak sustainability view comes from neo-classic economics, whereby business profit is central, and funds are spent on social causes and forestry to help protect the environment. Another definition of weak sustainability is that the three pillars can balance each other. For example, revenue can reduce environmental loss if activities damage the environment and help society. The British Petroleum sustainability performance model is based on a weak sustainability approach (Baxter et al., 2003) and is discussed later in this chapter.

There is a neo-liberal sustainability approach which highlights that sustainability aspects of evaluation should not violate the spirit of sustainability, unlike some approaches: "It does not matter whether the current generation uses up non-renewable resources or dumps CO_2 in the atmosphere as long as enough machinery, roads, and ports are built in a compensation" (Neumayer, 2003 page 3). It means that environmental capital, human capital, and economic capital are interchangeable, and only the net sum matters, which is classified as weak sustainability. Another definition of weak sustainability is that three sustainability pillars can balance the score if the net effect remains neutral or positive (Hartwick, 1991; Solow, 1991). Strong sustainability assumes that economic growth and social welfare cannot cause environmental damage. Strong sustainability exists where environmental protection is at the core of a business and its operations; activities are arranged in such a way so that they do not negatively affect the environment.

2.1.3 Sustainability evaluation

According to Pope et al. (2004), there are two sustainability evaluation and performance management approaches. When assessing sustainability, KPIs (key performance indicators) for gradual improvement is set over the specified period and monitored in the first approach. This method, called a 'top-downward' approach, is traditionally used in organisations; goals are set in one direction without understanding sustainability performance.

The second approach is called the bottom-upward approach, where assessment reference is the aspiration stage of the sustainability state in society's minds and a reference level. During this approach, companies aspire to attain the desired level of sustainability performance wished by society and stakeholders, and then they manage to control and improve (Pope et al., 2004). It is a pro-active approach where the current performance levels are first understood and gradually improved.

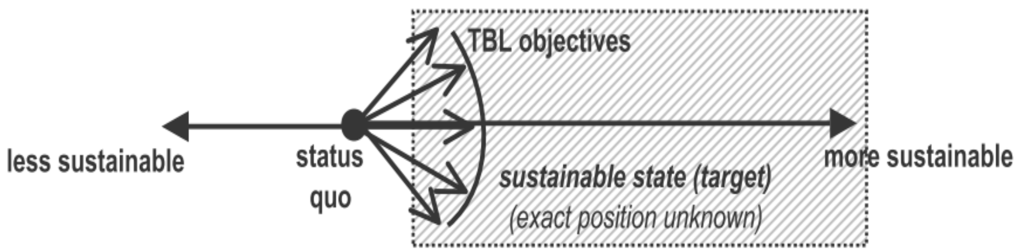

Figure 2-3 Objectives-led sustainability integrated assessment approach (Pope et al., 2004)

Figure 2-3 shows the traditional approach's sustainability status, where the status quo involves seeking to meet set objectives for either more sustainable or less sustainable conditions. From the discussion thus far, it is evident that in sustainability evaluation, the bottom-upward approach is suitable when the actual state of sustainability is evaluated, and gradual improvements are made by understanding and considering all the relevant factors.

2.2 Stakeholders' role

Corporate social reports (CSRs) are sustainability reports in the organisation and are often used to address stakeholders' concerns about the organisation's environmental and social sustainability performance (Lozano et al., 2015; Manetti & Toccafondi, 2012). Studies show that with increasing awareness of sustainability, climate change, and global warming, consumers and multiple stakeholders are now paying more attention to their actions and efforts regarding sustainability performance (Günther Bachmann, 2005). Like other scientific fields and sectors, the manufacturing sector is also under pressure to address sustainability issues. Industrial actions, environmental and social responsibility liabilities, challenges in the sector, and road mapping of future trends and actions are essential factors that need to be addressed to overcome today's sector's issues (Amini & Bienstock, 2014).

Research of over 2,500 companies listed in the Dow Jones Sustainability Index (DJSI) established the close relationship between stakeholders' expectations and organisational sustainability (Belal et al., 2018; L.-A. Ho, 2011). The companies surveyed were from all sectors, including manufacturing. They highlighted that all stakeholders' relevant concerns must be improved while developing a sustainability roadmap and robust evaluation approach. It is vital to develop a sustainability program by capturing internal and external stakeholder preferences in manufacturing and exploring the latest techniques and practices in the field (Belal et al., 2018; L.-A. Ho, 2011).

To develop a sustainability approach and select key elements, an organisation must consult its internal and external stakeholders to determine their preferences and account for their potential impact. CSR reports are mainly used to satisfy an organisation's stakeholders, from the manufacturer to end-users; this includes government bodies, NGOs, UNSD, and the general public. The latter needs to know the sustainability performance of the organisation and its general approach in this area. These stakeholders have sustainability expectations and concerns— the organisation should address these expectations and influence manufacturing with a sustainability approach. Companies that carefully manage sustainability issues and multiple stakeholders' expectations manage them (L.-A. Ho, 2011; Swartz, 2016).

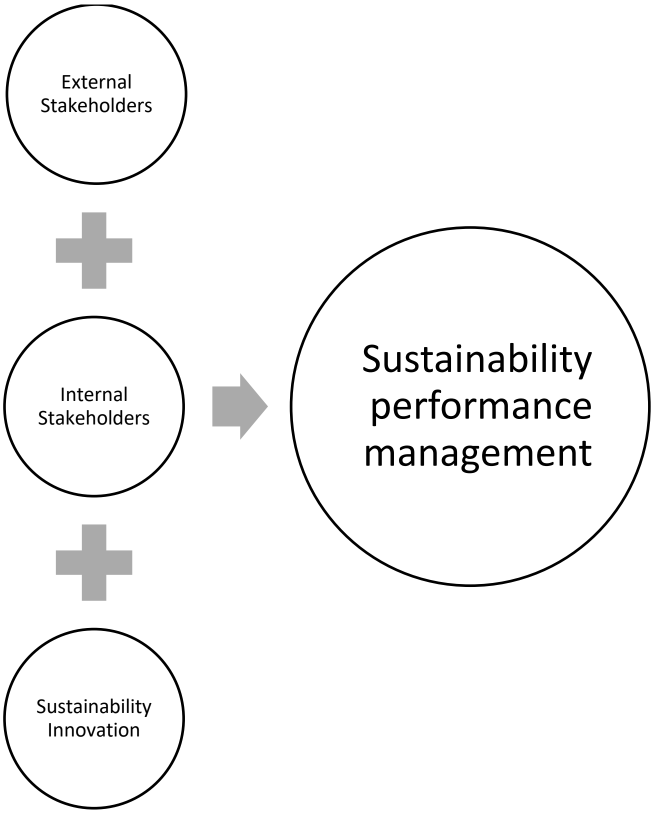

Figure 2-4 Stakeholders relationship for sustainability innovation adopted (L.-A. Ho, 2011; Lee & Raschke, 2020)

Figure 2-4 shows the internal and external stakeholders and sustainability innovation essential for sustainability performance management. Figure 2-4 shows a direct link and relationship of sustainability performance with internal and external stakeholders. The internal stakeholders are the manufacturer and the organisation's employees, including management, whereas external stakeholders comprise customers, immediate suppliers, contractors, end-users and consumers. The external stakeholder category includes the general public concerned about the impact of manufacturing on the environment, such as residents and close communities, NGOs, and environmental activists.

Different approaches, tools, and sources are available to determine current trends and demands; these include interviews, surveys, opinions polls, and groups using social media platforms. For sustainability thinking and practice to keep progressing, sustainability knowledge management is essential, such as investigating technologies used for maximising the use of available resources and materials. Some sustainability performance models define sustainability innovation (Research & Development) and performance management as different aspects of sustainability evaluation. Similarly, NIST considered Research and Development and Performance Management a critical sustainability dimension in sustainability evaluation (NIST, 2015). Sustainability innovation and performance management disciplines ensure the maximum utilisation of available resources such as land, plant, and equipment in the best order.

A good plan and solid teamwork are required to understand stakeholders' expectations and concerns and direct them to different sustainability indicators present in manufacturing to improve them (Oke & Aigbavboa, 2017). The ultimate goal of developing a sustainability performance approach is to improve the organisation's manufacturing process sustainability. It is becoming essential to accurately understand sustainability and develop a strategy to align company efforts to satisfy stakeholders, including consumers (BSR, 2008). Active stakeholder engagement in selecting and weighting sustainability elements and, further down the line, sustainability indicators are vital for sustainability performance management (Boiral & Heras-Saizarbitoria, 2020; L.-A. Ho, 2011; Lee & Raschke, 2020).

2.2.1 Multiple stakeholders' impact

The manufacturing sector demands an improved sustainability assessment methodology and a holistic approach to account for stakeholders' requirements; this last matter is often missing in assessment approaches (Indrianti & Kumala, 2016; Jayal et al., 2010; Swartz, 2016). It has been established that consumers (external stakeholders) and manufacturers (internal stakeholders) are not in agreement as to sustainability preferences in manufacturing (Fobbe & Hilletofth, 2021; Jayal et al., 2010). A flexible and customised sustainability assessment approach is required to account for the expectations of all parties concerned, especially the relevant stakeholders, and to develop a methodology that prioritises stakeholders' sustainability preferences in manufacturing (Fobbe & Hilletofth, 2021).

Every business has its own set of stakeholders that vary in expectations and level of influence. Some stakeholders have a significant influence on the manufacturing process and a strong influence on the business and vice versa. To manage risks inherent to a particular scenario and within a company generally, it has been established that a matrix develops as part of a coherent approach. This matrix takes stock of risks and their probability, accounting for stakeholders' expectations and management's influence. In risk management, the two factors involved in the assessment are the severity of that risk and the chance of its occurrence (Sivak, 2009). Then a multiplication matrix of risk and opportunities of happening develops a severity matrix.

The manufacturer should manage relevant stakeholders' expectations and understand their influence on the organisation. It will help the organisation utilise resources better and address multiple stakeholders (Sivak, 2009). The stakeholder's impact can calculate the similar patterns of evaluation risks management in an organisation, such as the probability of an event and the issue's intensity. In the following equation, stakeholders' impact calculation with the multiplication of stakeholder expectation in the organisation and influence comes from the stakeholder's impact calculation adopted from Olander (Olander, 2007).

Stakeholders Impact = Stakeholders Expectations * Stakeholders Influence Equation 2-1

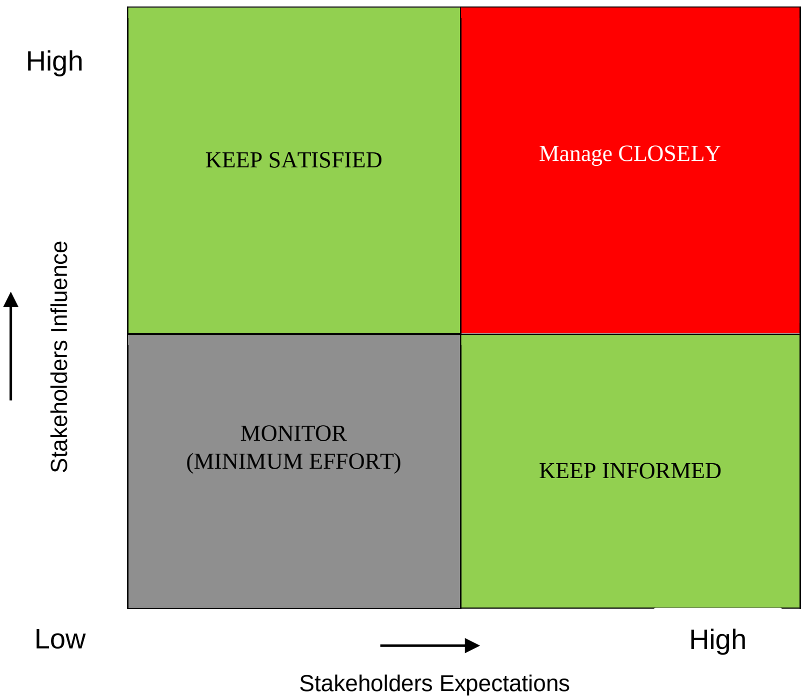

Figure 2-5 Stakeholder power grid considering stakeholders' expectations and influence. Adopted from (Olander, 2007)

Figure 2-5 shows the stakeholders' power grid about stakeholders' expectations and influence on the horizontal and vertical axis. The four quadrants show each stakeholder's four options when considering expectations and influence factors. Stakeholder impact is assessed by understanding their expectations about business (projects, manufacturing, NPD/EPD) and influence regarding the business's sustainability; this can include evaluations similar to approaches used in risk assessments (Olander, 2007). The stakeholder power grid prioritises sustainability elements and understands manufacturing preferences to manage the aspects (Boiral & Heras-Saizarbitoria, 2020; Bourne & Walker, 2008; Lee & Raschke, 2020; Olander, 2007).

Figure 2-5 is the stakeholder power grid matrix showing the potential impact of stakeholders on the project; the information should be handled according to a matrix based on the assessment score. Stakeholders with low expectations and less influence on manufacturing or services should lower weighting when prioritising manufacturing sustainability elements. On the other hand, those stakeholders' expectations with greater interest and concerns about sustainability performance should be given higher consideration; this is especially true when some stakeholders have high orders and stakes in the business and demand higher expectations from the organisation.

stakeholder influence					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	12
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5

stakeholder expectations

Figure 2-6 Stakeholders impact matrix showing the weight criteria

Figure 2-6 shows the stakeholder power grid with a numeric number developed after considering the stakeholders' expectations. The power grid matrix assesses the impact of stakeholders' quantitative impact in manufacturing. The stakeholder's expectations data could be obtained through surveys, interviews, and asking direct questions of weight from 1-to 5 or any chosen scale, whereas stakeholders' influence can be decided by manufacturing company management in business (Bourne, 2011; Bourne & Walker, 2008; Huse & Rindova, 2001; Olander, 2007). Multiple stakeholders' influence involves the organisation's supply chain should work in the manufacturer's knowledge or can assess through Delphi techniques or order books. The meeting point of stakeholders' expectations and influence decides the stakeholders' quadrant, and the manufacturer should use sustainability prioritisations in the manufacturing.

2.3 Sustainability boundaries for assessment

Sustainability boundaries are the limits and restrictions under which sustainability can define and evaluate measurements under consideration. In sustainability assessment, the sustainability charter is the main document, providing the company goals, objectives, and criteria to select system boundaries of sustainability in manufacturing. System boundaries in sustainability assessment provide limits, control, accuracy, and ownership for the manufacturer to evaluate sustainability in manufacturing (Mulcahy, 2012).

It is essential to define a system's boundaries and limitations during the evaluation process, as it provides ownership and control during the assessment process (Egilmez et al., 2013; Saisana & Tarantola, 2002; Ward et al., 2015). The selection of sustainability boundaries in assessment depends on the scope of the evaluation and its limitations. System boundaries in sustainability assessment can be defined as follows:

Gate-to-gate: This boundary approach assesses raw materials entering and finished goods leaving the factory gates. The gate-to-gate approach represents operations typically occurring in one location, making it convenient to manage and effective while providing better control for the manufacturer (Ny et al., 2008). Many companies are interested in understanding sustainability assessment with the gate-to-gate approach. It gives a fair evaluation of operations and processes in their manufacturing facilities (Venditti, 2014).

Cradle-to-gate: This boundary approach requires more detail than just the manufacturing function. It requires information about stages in the supply chain upstream as well, such as the extraction of raw materials, their transformation during the production process, and the supply chain system for the completion of finished goods, as shown in Figure 2-7 Cradle to Gate (1) and Cradle to Gate (2) highlight how the difference of entry and exit gate in manufacturing means before and after manufacturing in the supply chain.

Cradle-to-grave: This approach is in addition to the cradle-to-gate boundaries. It includes shaping materials to the end of the product's life cycle. Using commodities requires knowledge of the series of operations and how the product completes its life, from extracting raw materials to completing the life cycle.

Gate-to-grave: This system boundary starts from the factory gate and ends at individual end-of-life products. Hence, the consumer uses or operates it until it ends its life. This boundary evaluation usually provides a service life cycle.

Cradle-to-cradle (C2C): This is the most complicated approach to assessment as this approach envisions a future of absolute environmental sustainability based on the following two principles (Cradle, 2014):

Circular Economy: All materials and emissions (if not specified otherwise) benefit the environment or the Technosphere (i.e., the biological or the technical cycle, respectively). Products should be designed to pose no danger to human health and be recycled continuously. By complying with this principle, no waste is generated, and all outputs are inputs for other systems. Based on these cycles, closed-looped systems can be defined and established.

Strengthen renewable energy: Using renewable energy is crucial to effective design. The key to innovation is to design technically different products (i.e., avoiding "one-size-fits-all designs"). It involves matters such as the extraction of materials as well. It is not easy since various factors are involved in the assessment, including the mining and extracting materials, transportation, manufacturing, transportation to distribution centres, operational life, and finally, the end of life. There are many stages, much time and many parties and factors. Much larger carbon footprints generate during the cradle-to-cradle cycle. Much-preferred techniques are repurposing and remanufacturing, where the product did not reach the cradle (Brissaud & Zwolinski, 2017) and using the maximum inherent features of the product.

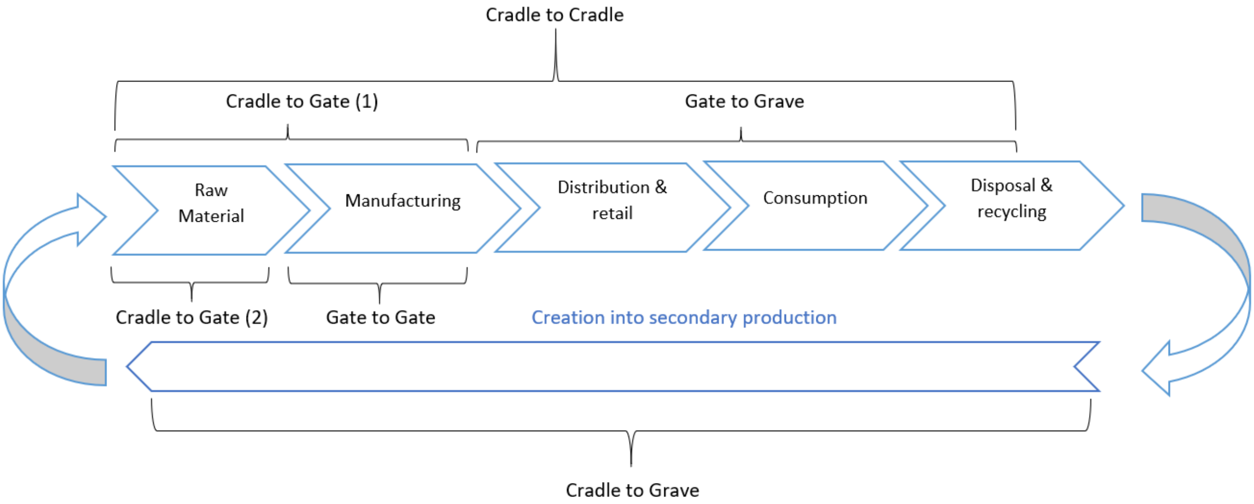

Figure 2-7 System boundaries in sustainability assessment in manufacturing

Figure 2-7 System boundaries in sustainability assessment in manufacturing show the system boundaries explained earlier. Of the five system boundaries in sustainability evaluation, 'gate-to-gate' is the more manageable for manufacturing. It provides more ownership and control for the manufacturer through different stages (Filimonau, 2016). The other system boundaries require more sophisticated data management, and in some cases, it is beyond the control of the manufacturing company and its capacity (Sarl, 2015). Government bodies and environmental agencies are more interested in manufacturers' reports on sustainability issues and prefer the gate-to-gate boundary approach (Essos, 2014; Trust, 2016).

A gate-to-gate boundary assessment is most comfortable with but has limited perspectives; however, manufacturing is more useful for the manufacturer to understand the manufacturing operations and take initiatives within organisation control. On the other side, government bodies are interested in net emissions. However, they need to split it further gate to the gate approach to make liable organisations for their actions in the complete supply chain.
According to Defra and Esos, government agencies are keener and expect the manufacturer to provide the sustainability and manufacturing data with a gate-to-gate boundary perspective.

2.4 A review of sustainability practices

A sustainability assessment review includes various approaches and models available in published literature or the industry. In sustainable manufacturing, industrial practices must consider three sustainability pillars, including environmental, social, and economic sustainability and investigate them in the processes, products and the supply chain (Faulkner & Badurdeen, 2014; Hallstedt et al., 2015).

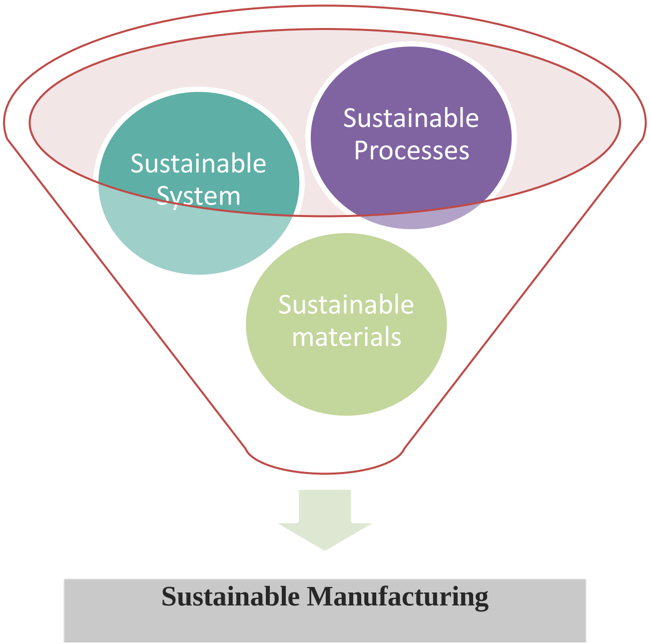

Figure 2-8 Sustainable manufacturing composition (Faulkner & Badurdeen, 2014)

Sustainable processes where manufacturing activities do not harm the environment, whereas sustainable materials denote illustration in manufacturing. Those coming from sustainable sources do not deplete Earth's natural resources, especially those finite. In cases where materials are finite, there should be a plan for their sustainability, ensuring that they are recycled or reused with minimum environmental impact. A 'sustainable system' means operations ranging from materials transportation to the entire supply chain system do not harm the environment, positively contributing to society and economic contribution to the system.

Seliger (2007) puts it differently when he argues that the manufacturing trade affects our society's environmental strength and technology. Two alternative ideas for sustainability are the 'precautionary principle' (Robert et al., 2005) and 'decoupling' (Cleveland & Ruth, 1998). Decoupling the environment is key to reducing the burden of human activity on the planet.

Minimising the energy used in manufacturing attracts additional attention since energy prices are increasing. Using less energy reduces the environmental impact (Rahimifard et al., 2010).

Sustainability improvement should also anticipate the problems throughout the spectrum within the industrial system process, product, and system (Despeisse, 2015; Hay, 2015; Jayal et al., 2010; Romli, 2015). Activities should be considered in their broader context and not in isolation, i.e. they should weigh up the broader impact on all system levels. If this is not undertaken, then improvements overall can be miserable. One should watch the broader system to confirm that local solutions are not producing more significant issues elsewhere or creating issues that negatively affect the process. If attention to the environment's impact is not factored in at the product's planning stage, this carries on throughout the life cycle (H. Zhang & Haapala, 2015). It influences how materials and resources are extracted and processed (Brunner & Rechberger, 2004) and manufacturing in the supply chain (Maxwell and Van der Vorst, 2003). It is widely recognised that decisions surrounding the choice of method Impact the entire product life cycle and supply chain (Paju et al., 2010) and are not well integrated with production systems planning (Ball et al., 2009). At the system level, the life cycle perspective considers the entire supply chain, product end-of-life within the infrastructure, and the broader involvement of all other factors for achieving this. In the material life cycle, a typical concept used is the 3Rs (Reduce, reuse, recycle), later extended to the 7Rs (reduce, reuse, recover, redesign, remanufacture, recycle & repurpose), the latter of which has been adopted in sustainable manufacturing (Kutz & Elkamel, 2010).

Alternative research fields in industrial sustainability are rapidly growing, such as Product-Service Systems (Baines et al., 2007), which provide chain integration with product and production systems (Srivastava, 2007). These ideas are often robust for trade to translate into sensible measures. Existing tools for environmental performance analysis and improvement are often sorted into four classes (Finnveden & Moberg, 2005; Nikulina et al., 2018; Robert et al., 2005) listed below :

1) Assessment, monitoring, and inventory
2) Engineering, design, and improvement
3) Environmental policies and enforcement
4) Prioritisation, management, and decision

These four classes mirror the topics thought about and steps required to move towards sustainable manufacturing. The primary step is quantifying the system's performance (assessment tools). It explained the emissions and technology standards or materials prohibition, monetary incentives and disincentives in the style of subsidies for research, effluent taxes and waste disposal fees, marketable permits such as CO2 emissions permits and tradable offsets and voluntary agreements, and targets (Kolk, 2000).

Numerous assessment tools and indicators in the literature and practice are used to quantify performance and progress, like life cycle assessment (LCA) and material flow analysis (MFA; Brunner & Rechberger, 2004). These tools measure ecological footprints (Galli et al., 2012) and sustainability indicators (Hák et al., 2007). They are multi-dimensional and might account for social, economic, and environmental impacts, water, energy, materials, and gas emissions. In particular, LCA may be an elementary assessment tool to gauge the environmental impact across its entire life. It is clearly outlined, and its use is standardised (ISO Life Cycle Assessment guidelines). However, the investment, time, and knowledge assortment requirements are vital. The LCA methodology complexities are often prohibitive, causing some companies to use a simplified version of the tool (Fortuin et al., 2013). It explained how each practice or approach works in general or in the manufacturing domain and where the gap exists. It did not suit the manufacturing sector regarding stakeholders' prioritisations and identifying the manufacturing functions involved in sustainability performance. Manufacturing functions are the various departments/sections in the supply chain working independently and coordinating with other functions.

2.4.1 Indicators-based approach

There are various approaches and models for sustainability assessment and performance in manufacturing. The approaches included qualitative and quantitative methods, but indicator-based and index-based approaches are preferred to attain operational efficiency and improvement in the decision-making process (Mangili et al., 2019; Mascarenhas et al., 2010; Stork et al., 1997). Indicators are critical for understanding and providing an in-depth assessment and detailed system performance (Stork et al., 1997). The indicator-based sustainability assessment approach provides room for improvement across various operational aspects of a business and assists decision-makers (Oecd, 2009).

Table 2-1 Summary of the review of sustainable manufacturing indicators set (Oecd, 2009)

Criteria *** strongly suitable for the purpose ** suitable if certain conditions met *may be applicable but not necessarily suitable Type of indicator set	Comparability	Applicability for SMEs	Management decision making	Operational performance improvement	Data aggregation and standardisation	Finding innovative products or solutions
Individual indicators	*	***	*	**	*	*
Key performance indicators	*	*	***	*	*	*
Composite indices	**		**	*	**	*
Material flow analysis	*	*	*	***	**	***
Environment accounting	**	*	**	***	**	**
Eco-efficiency indicators	**	*	**	***	**	***
Life cycle assessment	**	*	*	***	**	***
Sustainability reporting indicators	*	**	**	**	*	*
Socially responsible investment	**		**			*

Table 2-1 shows the benefits of using a distinct set of indicators in manufacturing. An individual set of indicators is instrumental in addressing issues in small to medium-sized enterprises. Key performance indicators determine how sustainable operations are and help guide management decisions. Composite indices can also help make decisions and support data management; these show the most critical issues and contribute to problem-solving. Using a material flow analysis can be very useful in improving operational performance. It can help find the best solution for producing sustainable products in a sustainable manner (Oecd, 2009).

Environment accounting indicators and the eco-efficiency life cycle analysis are handy in operational performance improvement. These indicators highlight areas of concern and inform management about the most sustainable materials. Overall, the indicators-based approach provides various advantages in sustainability assessment and clarifies manufacturing processes (Oecd, 2008, 2009). The indicators-based approach guides the decision-making process while managing sustainability in an organisation (United Nations, 2007).

2.4.2 Sustainable value stream mapping approach

Increased competitiveness in the manufacturing industry has led to corporations becoming competent, efficient, and sustainable in their manufacturing processes. To achieve sustainability, a company must thoroughly investigate the materials, product design, manufacturing processes, and overall supply chain. Sustainable value stream mapping (SVSM) is an approach that involves sustainable processes and systems in sustainable manufacturing. The method involves better manufacturing strategies in current and best practices and further improving them. Faulkner and Badurdeen (2014) used value stream mapping techniques with a lean environment toolkit and an EPA lean and energy toolkit. Junior and Gati (2009) used VSM to cut greenhouse gas emissions. (Simons & Mason, 2002) used a method of SVSM to increase the sustainability in product manufacturing by analysing and controlling GHG gas emissions. The SVSM approach has succeeded in simplifying processes already, reducing the number of activities needed in the manufacturing processes (Paju et al., 2010) proposed a new methodology termed 'sustainable manufacturing mapping' (SMM) which incorporates 'discrete event simulation' (DES) and life cycle analysis (LCA) using a conventional VSM technique.

Although sustainable supply chain stream mapping (SSC-VSM) benefits in assessing and improving manufacturing sustainability performance by cutting extra operations in the supply chain, it does not take full account of manufacturing operations and, more importantly, does not consider multiple stakeholders' expectations in the manufacturing supply chain. Various attempts have been made to develop VSM, incorporating environmental and social aspects into sustainability performance assessment. However, it does not account for stakeholders' role in prioritising sustainability elements and the manufacturing context (Megayanti et al., 2018).

2.4.3 Life cycle sustainability analysis

Life cycle sustainability analysis (LCSA) started with LCA and broadened to include sustainability's social aspects. LCSA is a comprehensive approach to sustainability assessment as it is a combination of LCA (which is predominately about environmental accounting), 'life cycle costing' (economic assessment) and 'social life cycle costing' (the social aspect of sustainability). We can then say LCSA equates to LCA, LCC, and SLCA's compound assessments and covers all key sustainability dimensions (Jørgensen, 2013). However, the LCSA approach does not account for sustainability assessment stakeholders when reviewing sustainability performance (Souza et al., 2015). The approach is useful and accounts for environmental aspects and covers social and economic sustainability but does not thoroughly weigh up manufacturers' and stakeholders' expectations in manufacturing. Research and development, as well as performance measurement, are also absent. Also, having a broader boundary system does not attract manufacturers and priorities multiple stakeholders, in manufacturing prioritisation.

2.4.4 Sustainability assessment model developed in the petrochemical sector

British Petroleum developed the sustainability assessment model (SAM) to assess operational activities on the environment and consider whether it can use in manufacturing. SAM approach uses 22 performance indicators to evaluate the environmental, social, and economic aspects of the full product life cycle in terms of sustainability performance; it also considers how resources are utilised (Baxter et al., 2003). The SAM approach is unique. It translates four sustainability dimensions into one currency on a like-to-like basis. It gives an overall assessment by merging four core sustainability pillars (social, environmental, resources, and economic). SAM*i* (sustainability assessment model integration) considers social, environmental, resource depletion, and economy. Then the net sum of all four dimensions makes the total score of SAM*i* show the net value.

Table 2-2 A summary of results of three British Petroleum projects (Baxter et al., 2003)

Projects	Social	Environment	Resource	Economy	SAM*i*
	%	%	%	%	%
Activity -I (Oil & gas exploration)	43.2	-19.0	-17.9	19.9	26.1
Activity –II (Landfill)	36.4	23.9	-17.2	22.5	65.6
Activity – III (Forestry	2.5	84.1	-3.2	10.2	93.6

Table 2-2 shows the sustainability reporting methodology for four sustainability pillars' aggregate sum of operational activities. The negative sign shows deterioration of environment and resources activity–I balance with social and economic gains. This conversion is an example of weak sustainability based on the overall consumption of resources; the net balance is positive since environmental damage is 'compensated' by economic and social gain. It means that there is no actual recovery for the damage done to the environment in real terms. The only compensation is for the company's growth, and substantial rehabilitation of the environment may take years to achieve success, resulting in weak sustainability. Its revenue compensates damage to the ground for various activities, including social employability (Day & Tosey, 2011; Pelenc, 2015). Many experts criticise this approach. (Pelenc, 2015) believes that natural capital and manufacturing capital are not interchangeable, so we cannot construct a comprehensive theory that compromises the environment.

The SAM model approach is limited to twenty-two sustainability factors and four dimensions and does not cover other aspects such as performance management and research and development. The 'SAM' model is an example of weak sustainability. It is questionable and not acceptable to many experts. Moreover, it does not account for stakeholders' preferences and expectations.

2.4.5 The integrated environment assessment model

Integrated environment assessment (IEA) results from assembling different methods to address specific issues and topics. One such issue is the overall environmental risk management process, and an IEA has a central role (Toth, 1998). An IEA:

- Directs efforts towards addressing ecological, social, and economic concerns to give an overview.
- Bridges gaps among scientists, researchers, and policymakers and identify areas requiring further research.
- Incorporates scientific knowledge, the latest technologies, and simulation tools to help identify critical concerns.

An IEA collates and processes information from various departments and makes it simpler for decision-makers to determine what action needs to be taken to meet targets. This tool helps assess environmental, social, and economic aspects but does not account for stakeholders' expectations in developing sustainability preferences. A fixed number of indicators have been assigned in the sustainability evaluation. However, an integrated approach has been designed to understand the net influence without sustainability stakeholders' feedback.

2.4.6 Lowell centre for the sustainability production model

The Lowell centre for sustainable production (LCSP) model uses sustainability indicators to determine a sustainable production model. The University of Massachusetts developed the LCPS. They selected twenty-two fundamental indicators not limited to one sector or manufacturing unit. Companies can increase this number depending on their particular operations and processes. The twenty-two indicators are placed in six main categories (Veleva et al., 2001):

- Energy and material usage
- Natural environment
- Social justice and community development
- Economic performance
- Workers
- Products

This approach involves five levels of assessment of each sustainability indicator; this helps determine the details each provides and, therefore, if it should be selected to represent an operation or not. The levels carry the following operational information of indicators:

Level 1 – Facility compliance/conformance indicator
Level 2 – Facility material use and performance indicator
Level 3 – Facility effect indicator
Level 4 – Supply chain and a product life cycle indicator
Level 5 – Sustainable system indicators

When selecting sustainability indicators, choosing one of five levels is essential. LCSP levels define each indicator's performance and set goals and targets in the manufacturing process. An eight-step close-loop model defines the benchmarks for all sustainability indicators. They can be measured, and targets reset depending on the new data received.

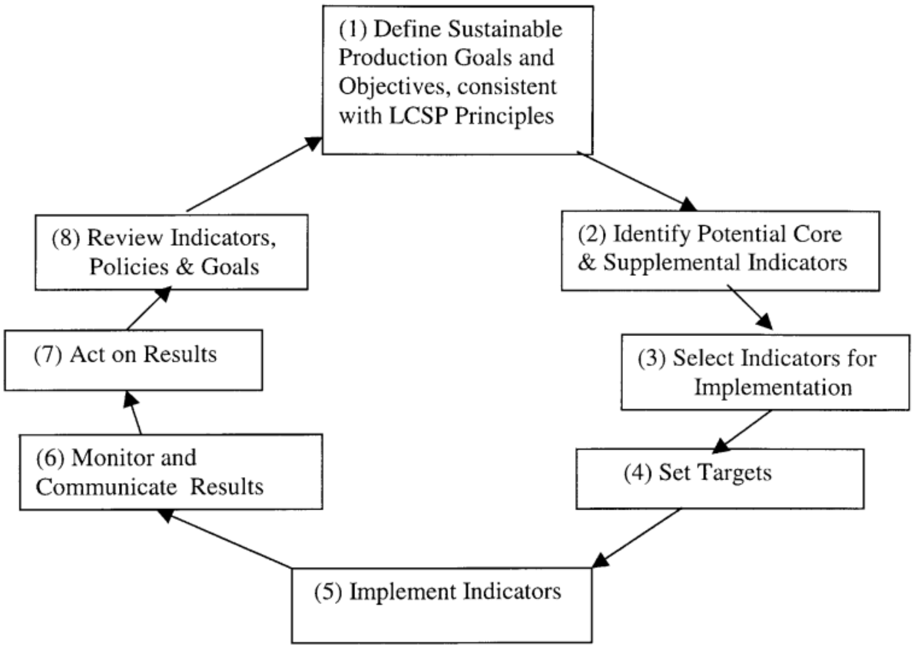

Figure 2-9 Continuous loops of assessing the sustainability of manufacturing organisation (Veleva et al., 2001)

The LCSP model describes qualitative and quantitative indicators for improving sustainability and guides calculating and setting target indicators. The model promotes standardisation and suggests many indicators covering global issues and continuous improvement. It encourages workers and company management to set targets and goals actively to improve sustainability performance.

While the LCSP focuses primarily on continuous sustainability improvement, it does not involve customers' or stakeholders' expectations and preferences. It is limited to and focuses on six areas with five levels of improvement.

The model works on the principle Do, Check, Act and Review and is better known as EMS (Environment management system) based on ISO14001. However, it is set to approach and cannot account for the stakeholder's expectations while prioritising sustainability functions. Organisation adopting this approach may neglect their relevant stakeholders and manufacturing operations since it does not account for manufacturing functions and prioritisation.

2.4.7 National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) has identified five sustainability pillars in sustainable manufacturing (see figures 1-6). These relate to environmental, social, economic, technological advancement, and performance management. NIST claims that the whole concept of sustainability cannot work without continuous research and development and performance management. Ongoing research provides an improved methodology to improve sustainability, while performance management helps utilise maximum output from the resources used in manufacturing.

NISTs developed a sustainable manufacturing indicator repository to help manufacturers select an appropriate sustainability indicator set and indices. However, these indicators span a variety of stages in business operations, not just manufacturing. NIST's list of sustainability indicators involved consulting 13 published sets of indicators and arranging them properly. This list is available for the manufacturing sector to choose the indicators most relevant to manufacturing operations. The drawback is that the plan does not incorporate stakeholders' expectations in prioritising these indicators, and it depends on the manufacturing organisation to select them. Without stakeholders' expectations, organisations might end up with resources for fewer priority functions and appreciated by relevant stakeholders who demand sustainability in manufacturing. The gap discussed in chapter 1 among multiple stakeholders, including the manufacturer.

Although manufacturing companies can select relevant sustainability indicators represented in their manufacturing, assess the supply chain, and then record and report an indicator-based sustainability assessment approach. However, this model is limited to manufacturer expectations in sustainability indicators prioritisations and does not provide a mechanism to add stakeholders' preferences in sustainability evaluation.

2.4.8 Global reporting initiatives guidelines

Another approach, Global Reporting Initiatives (GRI) guidelines, is commonly used to report on corporate social responsibility (CSR), and over 12,000 organisations use the GRI guidelines to do so (GRI, 2018). GRI reporting standards are discussed in detail in section 2.4.12. These guidelines are generic, allowing organisations from various sectors to pick and choose indicators relevant to their particular operations. The negative side of standards is that these are generally for all industries and not manufacturing-specific. There is no guidance to customise selection suitable for manufacturing stakeholders' expectations.

2.4.9 Dow Jones sustainability index to assess the sustainability of organisations

S&P and RobecoSAM maintain the Dow Jones sustainability indices (DJSI), an indicators-based approach to assessing organisations' sustainability. This criterion was developed by world business leaders and is a scoring mechanism including economic, environmental, and social dimensions that companies can use across different continents by considering companies' short- and long-term objectives (Jones, 2016).

Table 2-3 Dow Jones sustainability world index's corporate sustainability assessment criteria and weighting (Oecd, 2009)

Dimension	Criteria	Weight (%)
Economics	Corporate governance Risk & crises management Code of conduct/compliance/corruption and bribery Industry Specific	6.0 6.0 5.5 Depend on industry
Environment	Environment performance (eco-efficiency) Environment reporting* Industry Specific Criteria	7.0 3.0 Depend on industry
Social	Human capacity development Talent attraction and retention Labour practice indicators Corporate citizenship/philanthropy Social Reporting* Industry-specific criteria	5.5 5.5 5.0 3.5 3.0 Depend on industry

The DJSI approaches a company's total corporate sustainability score based on a predefined scoring and weighting value according to different sustainability indicators. The DJSI considers three main sustainability pillars, and under each pillar, there are indicators with predefined weighting values. These indicators are given discounts depending on the contribution to sustainability. The DJSI is useful but generic for all sectors, including manufacturing and retail (all listed companies must report sustainability performance based on the score set). It uses and merits organisations upon a limited set of sustainability indicators, and the scoring mechanism only covers environmental, social, and economic performance.

Additionally, the index fails to take stock of the most relevant stakeholders' priorities in the sustainability account and does not provide a methodology of how and where the improvement requires. A demanding sustainability approach in the organisation should have a method to understand relevant stakeholders' preferences and influence in a sustainability context and provide sufficient information for decision-makers to advise actions.

2.4.10 2005 Environment sustainability indices (ESI) approach

The 2005 Environment sustainability indices (2005 ESI) is an environmental policy-relevant gauge of national social and ecological conditions recognised worldwide. It consists of twenty-one indicators from seventy-six variables. All indicators are equally weighted in their consistent performance scoring. 2005 ESI indicators assess components at the national level to ascertain social and environmental conditions. It has five core components (elements; see Figure 2-10) and is limited to social and ecological disciplines.

Figure 2-10 Environmental Sustainability Index Building Blocks – Components (National & Stewardship, 2005)

Component	Logic
Environmental Systems	A country is more likely to be environmentally sustainable to the extent that its vital environmental systems are maintained at healthy levels, and to the extent to which levels are improving rather than deteriorating.
Reducing Environmental Stresses	A country is more likely to be environmentally sustainable if the levels of anthropogenic stress are low enough to engender no demonstrable harm to its environmental systems.
Reducing Human Vulnerability	A country is more likely to be environmentally sustainable to the extent that people and social systems are not vulnerable to environmental disturbances that affect basic human wellbeing; becoming less vulnerable is a sign that a society is on a track to greater sustainability.
Social and Institutional Capacity	A country is more likely to be environmentally sustainable to the extent that it has in place institutions and underlying social patterns of skills, attitudes, and networks that foster effective responses to environmental challenges.
Global Stewardship	A country is more likely to be environmentally sustainable if it cooperates with other countries to manage common environmental problems, and if it reduces negative transboundary environmental impacts on other countries to levels that cause no serious harm.

The index is maintained by collecting data from 146 countries. The ESI score represents environmental and social sustainability indicators. In this model, system boundaries cover many industries and are not specific to manufacturing. Again, this model does not directly consider the economic development of manufacturing companies. ESI concentrate on the environment and provides a framework for participating countries. The equal weighting of all indicators in performance scoring means that stakeholders' expectations and influence are not considered. Thus, each country's customised environmental sustainability assessment approach could better address the sustainability domain's development requirement (ESI 2005 Main report).

2.4.11 Environment Performance Index model

The Environment Performance Index (EPI) model denotes environmental issues in more than sixty countries. This index is derived via set objectives linked to the environment, policy categories, and indicators that make up the EPI.

Table 2-4 Environment performance index (Law et al., 2010)

INDEX	OBJECTIVES	POLICY CATEGORIES	INDICATORS
EPI	ENVIRONMENTAL HEALTH	ENVIRONMENTAL BURDEN	ENVIRONMENTAL BURDEN OF DISEASES
		WATER (EFFECT ON HUMANS)	ACCESS TO DRINKING WATER
			ACCESS TO SANITATION
		AIR POLLUTION (EFFECT ON HUMANS)	URBAN PARTICULATES
			INDOOR AIR POLLUTION
	ECOSYSTEM VITALITY	AIR POLLUTION (EFFECT ON ECOSYSTEM)	SULPHUR DIOXIDE EMISSIONS
			NITROGEN OXIDE EMISSIONS
			VOLATILE ORGANIC COMPOUND
			OZONE EXCEEDANCE
		WATER (EFFECT ON ECOSYSTEM)	WATER QUALITY INDEX
			WATER STRESS
			WATER SCARCITY INDEX
		BIODIVERSITY & HABITAT	BIOME PROTECTION
			CRITICAL HABITAT PROTECTION
			MARINE PROTECTION AREAS
		FORESTRY	GROWING STOCK
			FOREST COVER
		FISHERIES	MARINE TROPHIC INDEX
			TRAWLING INTENSITY
		AGRICULTURE	PESTICIDE REGULATIONS
			AGRICULTURE WATER INTENSITY
			AGRICULTURE SUBSIDIES
		CLIMATE CHANGE	GREENHOUSE GAS EMISSIONS/CAPITA
			ELECTRICITY CARBON INTENSITY
			INDUSTRIAL CARBON INTENSITY

There are indicators for achieving vital objectives for each policy category and meeting targets via sustainability indicators in specific locations. All indicators are weighted and then aggregated to assess environmental sustainability status. The overall score range is 0 to 100, 0 is the minimum, and 100 is the ideal condition. EPI represents the environmental situation in different countries using a factor-based approach.

Moreover, they have fixed categories and indicators that emphasise the environment, including its biodiversity. Although such indicator-based approaches represent different sustainability elements better, and their frameworks are excellent for comparison, they fail to study and account for stakeholders' expectations.

2.4.12 Corporate social responsibility approach to assessing the sustainability

Corporate Social Responsibility (CSR) reports are becoming common among large and medium-sized organisations (Essos, 2014; Trust, 2016). Consumer and stakeholders' expectations keep increasing, so they are taking more interest in the business regarding its environmental and social responsibility and manufacturing (Defra, 2013; Swartz, 2016). A corporate sustainability report is a preferred method among manufacturing companies to address the social and environmental performance attached to the business.

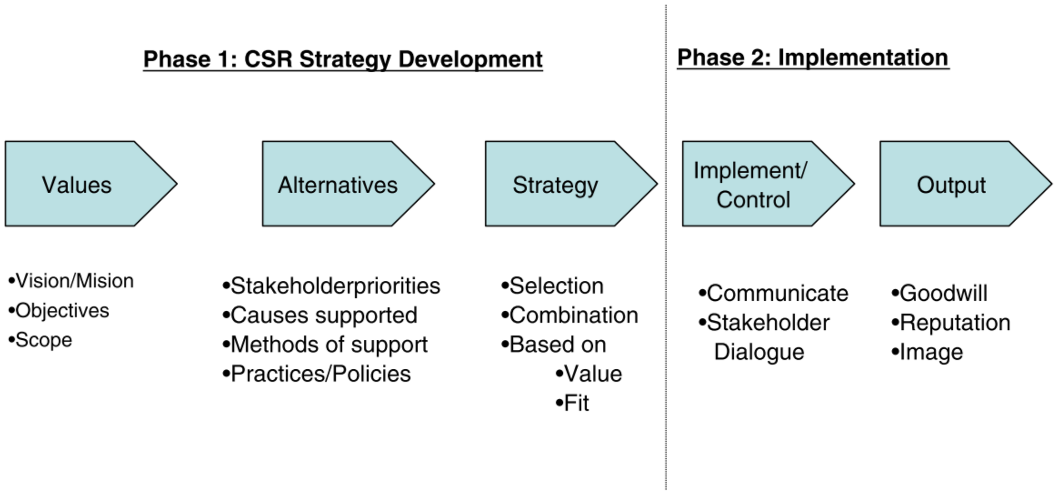

Figure 2-11 Steps to development of Corporate social responsibility reporting in the organisation (O'Riordan & Fairbrass, 2008)

Figure 2-11 shows the flow of corporate social responsibility reporting (CSRs) and the steps in its development of it. Most manufacturing companies report sustainability by publishing annual corporate social responsibility or 'corporate sustainability reports. These CSRs are flexible because companies can communicate their wishes to customers and stakeholders. Although GRI guidelines limit the organisation to particular elements, they still present a wide selection of sustainability indicators for manufacturers to produce their CSRs (Azapagic & Perdan, 2000; Defra, 2013; GRI, 2018; ISO-14031, 2013; United Nations, 2007). Some manufacturing companies have adopted selective sustainability assessment approaches and criteria to suit their supply chain system and selected social sustainability projects; they do, directly and indirectly, benefit their business goals. Nestle's company educates farmers about Nestlé's production and supply chain (Nestle, 2014).

Table 2-5 compares the numbers of sustainability indicators in manufacturing organisations to address sustainability issues. These indicators were assessed after consulting corporate sustainability reports of manufacturing companies under sustainability dimensions. Manufacturing organisations have similar operations yet have different indicators to gauge sustainability performance.

Table 2-5 Manufacturing companies using indicators approach to address sustainability

Manufacturing companies	Environment Indicators	Social Indicators	Economic Indicators	Reference
Coca-Cola	8	17	0	(Coke, 2014)
Pepsico	11	27	0	(Pepsico, 2013)
Nestle	12	22	0	(Nestle, 2014)
Procter & Gamble company	17	18	11	(P&G, 2014)
Unilever	31	32	0	(Unilever, 2014)
Distell	8	15	0	(Distell, 2014)
SMMT Driving Motor Industry	9	8	7	(Mikes Hawes, 2015)

Comparing manufacturing companies with different indicators (Table 2-5) shows no consensus on sustainability performance assessment or a group of indicators. However, the Food & Drinks sector started using GRI guidelines to report initiatives over the last two years. This approach allows customers and stakeholders to understand and compare organisational sustainability performance (Coke, 2017; Distell, 2017; Nestlé, 2015; Pepsico, 2016). Most large-sized organisations use GRI guidelines to address sustainability performance, including the manufacturing sector (GRI, 2018).

Manufacturing organisations mainly use corporate sustainability reports to address the responsibility of the environmental and social issue and keep economic reports separate, unlike P&G and SMMT driving motor industry, which also presents critical economic indicators to show the financial commitments and progress. These findings show that manufacturing companies, even those with similar businesses, are split about selecting sustainability elements and criteria. Many manufacturing organisations use stakeholders' expectations to prioritise sustainability elements (DEFRA, 2006; Romli, 2015; Swartz, 2016).

There is also no explanation in CSRs about how manufacturing companies use stakeholders' expectations to prioritise sustainability elements. It has a gap in managing the prioritisation of sustainability elements considering relevant stakeholders' expectations across the manufacturing sector. The alternative approach '3SM' provides an improved scheme to collate appropriate sustainability expectations from the stakeholders and use their potential influence in manufacturing to prioritise a sustainability gap.

2.4.13 The analysis of limitations of existing sustainability practices

Table 2-6 shows the extract of sustainability practices in the manufacturing sector and literature through academic search engines such as 'science direct'. Searches included 'sustainability frameworks' and 'sustainability assessment approaches in manufacturing'. Also displayed are sustainability frameworks assessed against sustainability pillars or dimensions such as environment, economic, social, research and development, performance management, and stakeholder expectations outlined in different studies (Jayal et al., 2010; NIST, 2015; Olander, 2007). This analysis explained practical current sustainability approaches and gaps when accounting for stakeholders' expectations and different sustainability pillars in manufacturing.

Table 2-6 Comparison of different sustainability practices

Sustainability assessment approaches	EN	SC	EC	RD	PF	ST	Source
Sustainable VSM (SVSM)	√	√	√				(Megayanti et al., 2018; Simons & Mason, 2002)
Life cycle sustainability analysis (LCSA=LCA+LCC+SLCA)	√	√	√				(Kloepffer, 2008)
SAM (sustainability assessment model indicator-BP)	√	√	√				(Baxter et al., 2003)
Integrated environment assessment (IEA)	√	√	√	√	√		(Andrea Déri, Darren Swanson, 2007; Toth, 1998)
Lowell Sustainability for sustainable manufacturing (LCSP)	√	√	√				(Veleva et al., 2001)
National Institute of Standard and Technology (NIST)	√	√	√	√	√		(Joung et al., 2013b; NIST, 2015)
Global Report Initiative (GRI)	√	√	√	√	√		(GRI, 2014)
Dow Jones Sustainability Index	√	√	√				(Jones, 2016)
2005 Environment sustainability indicators	√	√					(Etsy & Andonov, 2005)
Sustainability score system in manufacturing (3SM)	√	√	√	√	√	√	As discussed in the thesis

EN ~ environmental sustainability indicators
S.C. ~ social sustainability indicators
E.C. ~ economic sustainability Indicators
R.D. ~ research & development indicators
P.F. ~ performance management
ST ~ multiple stakeholders' expectations (Internal & external)

This comparison table also helps understand each framework's effectiveness in the manufacturing environment. It helps determine whether they are flexible enough to understand stakeholders' sustainability concerns and use them to prioritise sustainability elements. It is also for determining which framework has a specific application or can amend to assess manufacturing operations. It can also see if an integrated approach can be made, summing all the relevant indicators and providing meaningful action results (Muñoz-Torres et al., 2018; Poveda & Lipsett, 2014).

A split exists between stakeholders and manufacturers on prioritising sustainability elements and how to address them in manufacturing (Delai & Takahashi, 2011; Romli, 2015); an assessment approach should help solve this problem. After that, the task is to understand which framework or combination best integrates all the findings and provides data that predicts future sustainability trends. On this basis, the manufacturer can prioritise actions that promote sustainability.

Table 2-6 reveals that the multiple stakeholders' priorities in prioritising sustainability elements are not accounted for in most assessment practices. Comparing assessment approaches to stakeholders also highlighted the demand for an alternative sustainability evaluation approach that accounts for stakeholders' expectations (prioritisations about sustainability actions) and influence in manufacturing. The multiple stakeholder impacts (sustainability expectations x influence) built-in decision-making process and investigation of sustainability. These findings will provide the hotspots for the manufacturer to identify how to improve the sustainability and initiatives. Hotspots in the manufacturing are the high-priority areas/functions identified using QFD based approach and prioritising sustainability stakeholders. A hotspot justifies the manufacturer who needs to pay more attention and resources to improve the sustainability performance in manufacturing.

2.5 QFD tool for sustainability assessment

Toyota initially developed the quality function deployment (QFD) tool in the automotive sector in Japan's late 1960s. It is used in various applications and disciplines, such as designing and developing a product that addresses its requirements. It helps to build those features into manufacturing and services. Sometimes it is referred to as the advanced stage of 'Total Quality Control' (Warwick, 2007). QFD tool has potentially used in evaluating sustainability elements in the supply chain in manufacturing (Osiro et al., 2018)

QFD stands for:

- Quality: Understanding and the stakeholders' requirements about quality?
- Function: What must the design be capable of, and what is the focus of attention?
- Deployment: Who will do it, how will it be achieved, and when? (Planning)

QFD provides many tangible (reliability, product development, capturing customer expectations) and intangible (flexibility, the relationship between expectations and engineering design, communication and decision-making processes) benefits for all manufacturing and services sectors. A QFD-based approach captures stakeholders' expectations; it highlights a product's technical characteristics and features and prioritises actions by listing tangible and intangible aspects (Indrianti & Kumala, 2016). More than 160 scientific journals and publications have shown over 235 benefits of using the QFD approach in various disciplines (Institute, 2017). The effectiveness of QFD is not limited to manufacturing and product development but can extend to sustainable product development, digital manufacturing, and continuous improvement (CI) initiatives (Carnevalli & Miguel, 2008; Institute, 2017). A symposium that listed conference papers on QFD tool utilisation between 1989 and 2016 showed it had not been explored for sustainability assessment in the manufacturing sector (Carnevalli & Miguel, 2008; Institute, 2017).

In many industries, QFD has been effectively employed to improve the decision-making process, customer satisfaction, and product design and facilitate the prioritisation of performance measures by better understanding and capturing customers' voices (Carnevalli & Miguel, 2008). One of the tools used for environmentally friendly and sustainable manufacturing is Green QFD (GQFD) in the paper applications in sustainable manufacturing by incorporating relevant customer and stakeholders feedback (Romli, 2015). The concept of GQFD was a variant of the usual QFD methodology by integrating it with a life cycle approach

to product development. It is useful in many ways for evaluating different concepts for a company's manufacturing process, and it applies environmental requirements throughout the development process of a product (Y. Zhang et al., 1999).
A more sophisticated method approach to using the QFD tool developed known as GQFD – II (Y. Zhang et al., 1999); it includes the integration of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) into the QFD process. This approach accounts for raw material, manufacturing, assembly and disassembly, transportation, consumer usage, and disposal. The corporate performance comprises the strategic and operational goals, performance data (on the inventory level), the inventory data to sustainability key indicators, and the performance evaluation. It integrates the LCC approach into QFD matrixes and spreads product development cost, quality, and environment requirements to assess multiple product concepts.

Another variant of the novel QFD technique is Quality Function Deployment for Environment (QFDE); this method combines QFD with an Environmentally Conscious (E.C.) design. (Sakao, 2007) presented a concept incorporating environmental aspects into QFD to handle ecological and traditional products simultaneously. The methodology weighed and evaluated the effects of design improvements on environmental quality requirements (Sakao, 2007) and furthers the combination of an E.C. – QFD design with one that is more QFD-centred. Combining LCA with QFDE and inventive problem-solving theory can back the product planning, conceptualisation, and design stages. (Rathod et al., 2011) presented ECQFD and LCA's integration, surpassing its predecessors and allowing for a more detailed and sustainable product design methodology.

In (Romli, 2015), a new approach discussed different aspects of sustainability in the QFD process. This new approach used an ecological house of quality (Eco-HoQ) to address the quality function deployment (QFD) process and manage sustainability considerations in a single place. It ensures the significance of information and helps improve sustainability in each phase of the design process. ECQFD (Environment conscious quality function deployment) and LCA tools are being used in sustainable product development of electronics and rotary switches (Y. Zhang et al., 1999). The sustainable product development approach integrates with ECQFD and LCA to ensure sustainable product design in manufacturing.

The QFD tool is favourable for assessing suppliers and considering stakeholder desires (W. Ho et al., 2011). (Benner et al., 2003) presented a research study demonstrating how stakeholders can use QFD to differentiate between suppliers. However, it has methodological difficulties while addressing the customers' perspective (Carnevalli & Miguel, 2008). The integration of the Fuzzy-QFD method solved these minor difficulties. The fuzzy-QFD approach addresses the concerns of suppliers and customers (Bevilacqua et al., 2012).

Some studies highlight the potential benefits of using the QFD tool in sustainability. These advantages include selecting the most sustainable processes and the strategies for facilitating a more systematic and quantitative analysis of the data (Carnevalli & Miguel, 2008; Institute, 2017; O'Hare, 2010). However, to date, no research has been done using the QFD-based approach in sustainability performance assessment in the manufacturing sector. A hybrid QFD-based approach has been identified in the literature for the sustainability assessment in manufacturing (Abdel-Basset et al., 2019).

2.5.1 QFD tool structure and functions to prioritise preferences

QFD tool captures customers/stakeholders' voices and develops engineering/operations to address the concerns. The relationship between customers' preferences and engineering characteristics provides meaningful information to the organisation, what to do, and the rating of the engineering characteristics. Finally, it uses other quality and process tools such as the Taguchi method to align further stakeholder interests and functional requirements (Warwick, 2007). The QFD tool has two primary functions:

(i) To develop or design a product/service to meet customer expectations.
(ii) To develop quality parameters before the launch/production of services or products.

The QFD process follows logical steps by examining the organisation's strategic objectives and customer requirements. It evaluates its capabilities to match and fulfil customer requirements and expectations. The QFD-based methodology processes information for decision-makers to better understand stakeholder expectations and which sustainability elements to prioritise. It has the following advantages (Warwick, 2007):

- A better understanding of customer and stakeholder needs
- Incorporating stakeholder expectations into product or services design
- Prioritising stakeholder demands
- Identifying the technical characteristics needed to meet stakeholder expectations in products or services

- Determining areas needing improvement and areas in manufacturing and services that need attention

The QFD-based approach can bridge the gap between manufacturers and stakeholders in sustainable manufacturing by understanding and better processing stakeholders' expectations and influence.

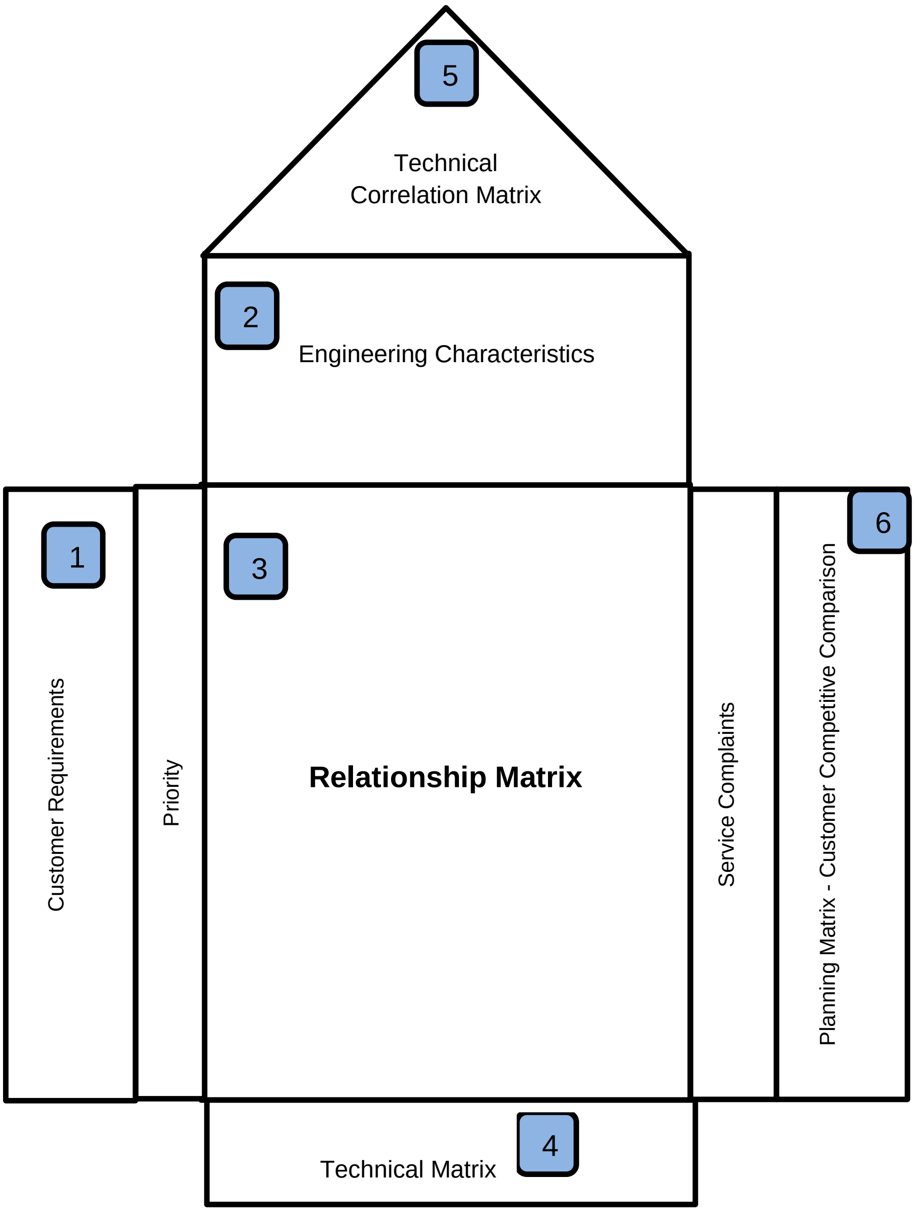

Figure 2-12 The structure and essential features of the quality function deployment tool adopted (Warwick, 2007)

Figure 2-12 shows a structure and overview of the QFD tool and the different sections.
Box' 1' denoted in the structure pertains to customer requirements. It includes needs and wants, as determined through market research.
Box' 2' shows a product's or service's engineering characteristics for optimal performance.
Box' 3' is essential in developing the relationship between stakeholders' needs and engineering characteristics. This relationship could range from 'no relationship' to 'strong relationship'.
Box' 4' denotes a technical matrix that indicates the technical priorities based on the relationship between customer requirements and engineering characteristics. It also provides quantitative design targets for each engineering characteristic based on scientific preferences and competitive benchmarking.
Box' 5' signifies the technical correlations of how the engineering characteristics may be mutually supportive or contradictory.
Box' 6' provides the quantitative market data for each customer's expectations — these values are based on user research, competitive analysis, and team assessment. QFD processes the following information so that stakeholders' demands are prioritised:

- Customer and stakeholder expectations
- Design requirements
- Engineering characteristics
- Operations requirements
- Working procedures

The QFD structure and process are explained in the following sections and demonstrate how meaningful information is extracted from stakeholder expectations and added to the QFD matrix to generate meaningful information.

2.5.1.1 Multiple stakeholders' input

Before developing goods or services, an organisation needs to understand markets' requirements, stakeholders' expectations, and sector requirements. The QFD tool translates stakeholder expectations and needs into products or services. Organizations that successfully understand their stakeholders' expectations and translate them into products or services gain a market advantage. When using the QFD tool to assess stakeholders' prioritisations, it is essential to be familiar with the following concepts:

- The stakeholder chains.
- What is meant by 'stakeholder' in the QFD tool?

- Obtaining stakeholder expectations and translating them into functions.

The stakeholder chain links future and previous parties to the supply chain; stakeholders in QFD denote different individuals or parties directly or indirectly involved in the business or influence it.

2.5.1.2 The stakeholder chains

It is essential to understand the business stakeholders and determine the driving force between the final design specification based on the final user's profile. Some businesses have direct customers, whereas others have a chain of them and more than one stakeholder involved in operations. Customer chain means that multiple customer or stakeholder is applied at different supply chain stages. Understanding customer requirements at each stage is essential before designing any product or service.

Examples:

Manufacturer's Product Customers

1) Bottled Milk (Supermarket - parents who buy – a child who drinks)
2) Aircraft seat (Aircraft manufacturer – aircraft lease company - travel agents – airline passengers)

The customer chain analysis provides the details of the immediate company customer and the end-user. It provides details and links to the customer chain at different supply chain levels, highlighting essential interactions. Most of the stakeholders in the supply chain are customers of earlier stakeholders in the chain. Therefore, each stakeholder needs to understand their immediate customer and influence in the supply chain.

2.5.1.3 Organising stakeholders' preferences

Studies have indicated that considering multiple stakeholder expectations and knowledge in the design of products and services improves its sustainability (L.-A. Ho, 2011). Organising the stakeholders' requirements is an essential step in restructuring. It allows all members to clearly define the expectations put forth to them and define the scope by prioritising necessities based on time, cost, and expertise. QFD tool prioritises stakeholders' requirements.

- Organise stakeholders' preferences and prioritise them based on need, necessity, and outcome.
- To translate stakeholders' requirements into technical characteristics.
- Understand and address stakeholders' preferences and expectations for product/service features.

2.5.1.4 Technical and regulatory requirements

There are some requests that customers cannot identify during surveys or interviews, so expert or legal understanding is required to design those characteristics into the product or services. Regulatory requirements are rules mandated by governments and international bodies that companies must comply with before introducing the product into specific markets. They mostly involve quality requirements and health and safety issues. The manufacturer's responsibility is to ensure that all these requirements are met, even if the customer does not express them explicitly during the study. These technical and regulatory requirements are listed in a tertiary matrix and customer expectations and needs (Warwick, 2007).

2.5.1.5 Establishing the stakeholders' rating

After collecting stakeholders'/customers' expectations, it is essential to prioritise stakeholders' expectations to be allocated.
Two things need to be considered while assessing customer expectations:

- How much weight does each indicator hold at the tertiary level?
- How should a company respond to each stakeholder prioritisation requirement?

The QFD matrix will further process the customer requirements and prioritise them in the product or service design. In recent years, rating-scale and multi-criteria decision-making and analytical hierarchy process tools have been widely used in energy sustainability assessment. They are frequently found in recent surveys measuring subjective attitudes and beliefs (Jon A

Krosmick, 1997). Multiple or Multi-Criteria Decision-Making (MCDM) is a branch of operational research that evaluates multiple conflicting criteria; this assists management during decision-making by accurately weighing up contradictory data covering cost vs safety (Jon A Krosmick, 1997; A. Kumar et al., 2017). It minimises uncertainty, enhances decision-making, and prioritises goals and targets. An analytical hierarchy method is a tool (Pohekar & Ramachandran, 2004). Many sustainability models use this technique, including the DJSI, the 2005 ESI and the EPI.

Table 2-7 Reference made on a scale from 1- to 5

AHP Scale of importance for comparison pair (aij)	Numeric Rating
Not at all important	1
Not Very Important	2
Somewhat important	3
Very important	4
Most important	5

A scale of 1 to 5 in MCDM is appropriate, where a comparison between multiple elements is required (Learning and Teaching Centre, 2010). In organisational surveys, it is crucial to understand and judge this subjective aspect and reflect it in matrices; this is especially true regarding reported satisfaction levels (Pounder, 1999). A rating scale from 1 to 5 can help highlight differences among respondents regarding how they value different aspects of a product or service (Jon A Krosmick, 1997; Learning and Teaching Centre, 2010; Pounder, 1999).

2.5.1.6 Establishing engineering characteristics

Using the QFD tool's critical task is determining stakeholders' expectations and then translating those expectations into engineering features. The engineering characteristics must reflect stakeholders' expectations since management wants their input to influence the product or services. The QFD team must translate customer requirements into engineering characteristics; focus groups and brainstorming sessions are useful for discovering stakeholders' expectations since they reveal stakeholder satisfaction levels, as discussed earlier (Warwick, 2007). Stakeholders' requirements must be translated into measurable and quantifiable engineering characteristics and a language meaningful to the designer. A QFD team is usually employed, along with the support of a few experts on the topic.

2.5.1.7 Technical competitive comparisons

The QFD matrix contains a comparison feature that allows companies to understand and compare themselves against serious competitors. It is about comparing company products, features, or service attributes. Methods depend on the type of product/service:

- Consumer product: buy it, experience it, and then 'reverse-engineer' it.
- Computer program: experience it and benchmark characteristics against the company's program.
- Service: Buy the service, experience the process, record feedback, and compare it with competitors.

The engineering characteristics must be organised into categories to allow for comparative analysis. These comparisons provide hard facts about competitors and are evaluated by a standard company test.

The manufacturing functions or product attributes can match a competitor's by rating it through a market survey and a side-by-side comparison with its competitors' attributes. The comparison provides the background for understanding its strengths and weaknesses and improving areas to increase its market share.

Continually monitoring a company's competitiveness and comparing it to other players in the market provides a framework by which the company can set out a strategy for gaining an advantage. It also assists in determining which areas to invest in, so the company continues to grow. Some companies outsource this research to remain impartial and thus receive a better overview of their product performance than their competitors.

2.5.1.8 Engineering characteristic rating

This rating is a combination of engineering characteristics and stakeholders' expectations. The combined data show how much individuals value product development and customer expectation. Values are assigned to the correlated symbols. The recommended values are:

Strong relationship ●= 9

Medium relationship ○= 3

Weak relationship ▽= 1

No relationship (considered blank, 0)

A further rating is given by summing the figures in each column. It sums up how important the customer views the various aspects of the product — and a rating and correlation are assigned.

The QFD chart provides the 'importance rating' after processing the customers' expectations and incorporating engineering characteristics into the matrix. Not all the engineering characteristics have the same weight in the matrix; those more critical in customers' or stakeholders' eyes have a higher weighting, and manufacturers should consider them according to their value.

Engineering Functions			Stakeholder Expectations	Air bags, ABS & assisting camera's to read lanes	0-100 mph speed in 21 seconds	7 seaters and 24L boot size	Optional colours & interior design	70 mpg on motorway	For targeting 70% of market segment
New Car development	Engineering	Safety of the car (ABS)	4	●	○				●
		Speed of the car (1-100mph)	3	●	●	●	○		
		Capacity of the car (capacity, engine size)	5	●		●		○	
	Utilities	Economy (fuel efficiency)	2	●		●	●		
		Customised Options	3		○			○	
		Cost of the car	3		○			○	
Prioritisation of elements considering stakeholders expectations				126	45	90	37	33	36

Figure 2-13 Engineering characteristics importance rating considering customer expectations (Warwick, 2007)

Figure 2-13 shows that the bottom row shows the QFD matrix value after processing customer expectations against the relationship's engineering characteristics. The score calculated in the QFD sheet addresses stakeholders' most important elements and expectations. The higher the value, the higher the importance to the stakeholders. Prioritising the data helps guide the manufacturer by showing which aspects of the manufacturing process require the most attention. QFD tools, in a way, can improve not limited to sustainability products but also the efficiency of sustainability processes (Rihar & Kušar, 2021).

The literature review identifies QFD tools, such as the relationship development between customers' voices and engineering characteristics. This results in prioritising engineering characteristics and operations to address customers' preferences in the product. This feature can modify and prioritise the engineering operations with the relationship of stakeholders' preferences. A modified QFD tool body can also develop a relationship among the same sustainability elements to prioritise and multiply multiple stakeholder preferences and influence to rate different sustainability elements.

Today, the average consumer has numerous options available when selecting products and services. To remain competitive, organisations must determine what drives the consumers' perception of value or quality in a product or service (Warwick, 2007). Many companies use a structured process to help define their customers' wants and needs, transform them into specific product designs, and process plans to produce products that satisfy them. They use the process or tool called Quality Function Deployment (QFD). Warwick (2007) defines QFD as a tool used to determine customer requirements and convert them into detailed engineering specifications and plans to produce the products that fulfil those requirements (Warwick, 2007). QFD translates customer requirements into measurable design targets and drives them from the assembly and down through the sub-assembly, component, and production process levels. QFD methodology provides a defined set of matrices to facilitate this progression (Warwick, 2007).

Effective communication is one of the most important aspects of any organisation's success. QFD methodology helps communicate customer needs effectively throughout an organisation's business operations, including design, quality, manufacturing, production, marketing, and sales (Puglieri et al., 2020). This effective communication allows the entire organisation to produce products that customers perceive to be highly valued. There are several additional benefits to using QFD:

- Stakeholders focused: QFD methodology emphasises the customer's wants and needs, not what the company believes the customer wants.

- VOC competitor analysis: QFD entails a 'House of Quality tool that directly compares your design or product to the competition in meeting the VOC (voice of the customer). This quick analysis can be beneficial in making design decisions that could give a competitive advantage.

- Shorter development time and lower costs: QFD reduces the likelihood of late design changes by focusing on product features and improvements based on customer requirements. Effective QFD methodology prevents valuable project time and resources from being wasted on developing features or functions that add no value.
- Structure and documentation: QFD provides a structured method and tools for recording decisions made and lessons learned during the product development process. This knowledge base can serve as a historical record to aid future projects. Companies must bring new and improved products to market that meet customers' actual wants and needs while reducing development time. QFD methodology is for

organisations committed to listening to the voice of the customer and meeting their needs.

This discussion identifies the suitability of the QFD approach for capturing and understanding the multiple stakeholders' expectations, a gap identified in current sustainability assessment approaches. It is suitable for the potential development of the new sustainability assessment approach.

2.6 Summary of the research gaps

The literature review highlighted the split about sustainability prioritisation among multiple stakeholders. This refers to the manufacturer adding more value to some sustainability elements, which is not demanded and expected by other stakeholders. Simultaneously, the manufacturer wanted to produce and manage sustainability performance to satisfy multiple stakeholders' expectations, which generated the demand for an accurate sustainability assessment approach.

Simultaneously, a rationale analysis of current sustainability approaches in practice and available literature pointed out a lack of stakeholders involved when setting a criterion about sustainability's prioritisation. Most sustainability approaches are either generic or weightage to a particular sustainability pillar (such as environment, social, economic) or suitable in different boundary systems (geographical situation and boundary system explained in literature) and not ideal in the manufacturing environment.

The literature review also identified that the QFD tool has potential and is being used in the sustainability assessment (Puglieri et al., 2020) and in prioritising sustainability indicators accounting for the role of multiple relevant stakeholders. It realised that a combination of modification QFD tool, AHP and Normalisation methods, and multiple stakeholders' expectations and influence could provide meaningful information for the manufacturer to install in manufacturing with local knowledge that can fit the purpose.

2.6.1 Research questions

Through the literature review and discussion, the following research question arose from a structured literature review understanding the importance of the sustainability assessment approach in manufacturing highlighted in various researches (M. Kumar & Mani, 2022); the following research questions arise: guide the study.

1. What are the current sustainability assessment approaches practised in the manufacturing sector, and what are their limitations?
2. How can sustainability be assessed more robustly, flexibly, and precisely in the manufacturing sector while incorporating stakeholders' expectations?

2.6.2 Aim & Objectives

The thesis aims to present a state-of-the-art approach toward sustainability assessment in manufacturing and fulfil the purpose. The following are the goals and objectives of this research work.

1. Criticise the manufacturing context's benefits, limitations, and gaps in the available sustainability assessment approach.
2. Design a robust and accurate sustainability assessment framework for manufacturing that decision-makers and manufacturers fully understand.
3. Design stakeholders to include stakeholders' role in sustainability performance assessment and identify the manufacturing operations that require attention.
4. Validation of the sustainability assessment model in a manufacturing environment.

The Sustainability Score System in the Manufacturing (3SM) model has been proposed and developed after examining the different practice approaches and understanding the gaps in sustainability evaluation practices. After development, the '3SM' model was validated through a pilot study using current manufacturing data in a manufacturing environment using a 'gate-to-gate' system boundary. The '3SM' model was presented to a manufacturing company during the development phase and was updated using company appraisal and recommendations. It was then used for validation through a cross-functional team by collating relevant stakeholders' feedback and gathering sustainability data used in manufacturing. After validation, the model was presented, and the outcome was shared with company management for their input and appraisal regarding the applicability, usefulness, and relevance to the manufacturing environment.

These objectives are discussed in detail in the coming chapters of this research work.

Table 2-8 Research objectives, issues, methods used and contribution summary

Research objective	Research Issue	Relevant section	Research method	Contribution of work
Criticise the manufacturing context's benefits, limitations, and gaps in the available sustainability assessment approach.	Most existing sustainability assessment approaches are not relevant to manufacturing.	Chap # 2.	Literature review.	A review of sustainability assessment approaches is discussed in the literature review, and a comparison is drawn considering specific sustainability dimensions, especially stakeholders' involvement.
Design a robust and accurate sustainability assessment framework for manufacturing that decision-makers and manufacturers fully understand.	Most sustainability assessment approaches are generic: they do not target any manufacturing discipline or identify problem areas in manufacturing functions.	Chap # 4.	Delphi techniques, Surveys, Interviews, Group Discussions, Pilot study, Quantitative approach.	An indicator-based approach uses a scoring system to understand the situation and help decision-makers require urgent attention.
Design stakeholders to include stakeholders' role in sustainability performance assessment and identify the manufacturing operations that require attention.	Most sustainability approaches do not incorporate relevant stakeholders' expectations in performance criteria and are generic for all sectors.	Chap # 4.	QFD-based approach, Normalisation Approach, Surveys, Quantitative approach.	The sustainability score system has prioritised a QFD-based approach incorporating relevant stakeholders' (internal & external) expectations and their influence on manufacturing and manufacturing functions.
Validation of the sustainability assessment model in a manufacturing environment.	Most of the current sustainability assessment approaches are not relevant to manufacturing.	Chap # 4 & # 5.	Survey, Interviews, Group discussion, Delphi Techniques.	The proposed sustainability (3SM) model applicability and relevance were checked through validation in the manufacturing sector using the manufacturing team's actual sustainability data.

2.7 Summary of chapter

This chapter starts with the concept and meanings of sustainability, sustainability value, and sustainability role in manufacturing. It explains that sustainable manufacturing is possible when sustainable processes and sustainable materials are used in conjunction with a sustainable supply chain design in the manufacturing process. A rational analysis of manufacturing companies with a sustainability approach exists in the manufacturing sector; this includes selecting indicators that represent sustainability. These indicators include environmental, social, and economic aspects. Companies outside that sector possess similar business and operational models but have a different approach to sustainability. These factors are the current limitations of sustainability frameworks practised and those advanced in the relevant literature. It shows that existing approaches are too general or too specific for businesses to use effectively. Therefore, there is a lack of an integrated approach that meets companies' needs requiring a comprehensive evaluation of their manufacturing sustainability.

Using each manufacturing sector approach has limitations and benefits in discussing sustainability. Research shows a gap in sustainability evaluation and preferences between manufacturers and internal and external stakeholders. There is a need for a framework to help manufacturing organisations select relevant sustainability indicators and help decision-makers understand manufacturing practices' performance.

Then there is an outline followed by a detailed description of the method and structure of the overall QFD tool along with its different parts and how they work together to explore and collate customers' and stakeholders' expectations for new product and service development. Another discussion was that although QFD is well established in product and service development, it has not been used to assess stakeholders' expectations regarding sustainability performance and evaluation in the manufacturing sector. Furthermore, this chapter reflects how the stakeholders' influence is also essential when determining sustainability; some stakeholders are more influential than others when persuading manufacturers about shaping sustainability in the organisation.

Subsequently, a discussion ensued about the challenges and gaps in sustainability evaluation in the manufacturing sector and the requirement for a flexible and customised sustainability approach that takes proper company stakeholders' account. Such an approach needs to understand different stakeholders' expectations and develop a plan for prioritising the key features of sustainability. Moreover, it must measure performance by considering manufacturers' and stakeholders' interests without compromising sustainability's core elements.

Chapter 3 Research design

The word 'research' comprises two syllables: ***re*** and ***search***. It means searching for a topic systematically to find the right answers (Richard M. Grinnell, Jr., 2010). Creswell defines it as a process of collecting and analysing information to increase our understanding of a topic or issue' (Hejres et al., 2017). The research employs a combination of inductive and deductive approaches to answer questions. It may be 'pure' to find advancement on the topic or 'applied' to use more practical solutions to answer questions (Blaikie, 2000; Easterby-Smith, Richard Thorpe, 2012; R. Kumar, 2011). The above definitions infer that research is a planned activity to increase knowledge about particular phenomena.

3.1 Research layout

This thesis comprises six chapters, as shown in Figure 3-1. The literature review demonstrated a gap between manufacturers' and stakeholders' expectations and requirements. Thus, the need for an improved sustainability assessment approach became clearer. This chapter will discuss the research methods and philosophy adopted to answer the research questions and meet set objectives regarding research design.

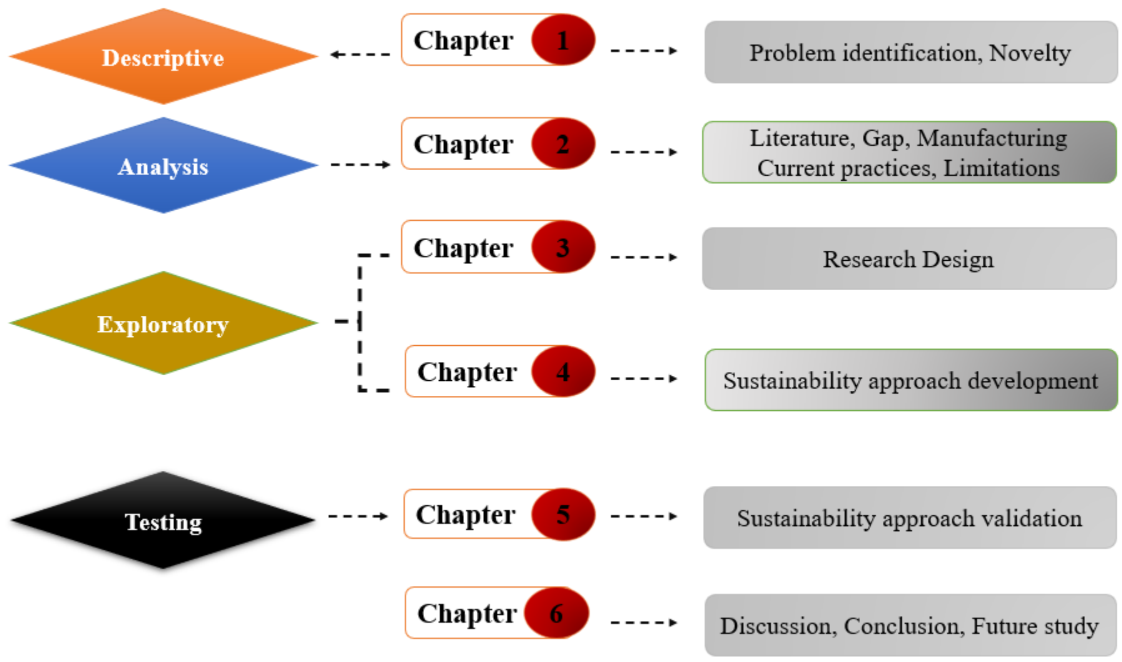

Figure 3-1 Outline of the research thesis

In Figure 3-1 outlined the structured approach of the written thesis and how through literature review, identified the research gap and then developed research questions and objectives. It outlined that structured literature led to identifying a QFD-based approach suitable for capturing multiple stakeholders' expectations. The approach and thesis outline are divided into three main phases (exploration, explanation, and testing) and combine various approaches to understanding and using existing knowledge. In chapter 4, a method presented for sustainability assessment in the manufacturing environment and then approach further passed through pilot and full validation in manufacturing environment using manufacturing data.

3.2 Research Theory

According to Shuttleworth (2008), 'In the broadest sense of the word, the definition of research includes any gathering of data, information, and facts for the advancement of knowledge' (Shuttleworth, 2008; Terre Blanche et al., 2006). Adopting the appropriate methodology is essential for ensuring a stable platform for different research operations and making research as efficient as possible, gathering the maximum amount of information with minimum effort, resources, and time. It is essential that the inquiry process is controlled, systematic, critical, and auditable (Blaikie, 2000; R. Kumar, 2011).

3.2.1 Positivism

Positivism is a research philosophy that has its roots in physical science. Prevalent in the early 20th century (Guba & Lincoln, 1994; R. Kumar, 2011), most assumptions have been challenged, but they remain widespread in physical science and applied to engineering (Reich, 1994). Positivism carries considerable weight among natural scientists since it involves observation and outcomes (Saunders et al., 2008). It holds the following values:

- Ontology: Objectivism is central when considering ontology in positivism (Hay, 2015; Tosey & Mathison, 2010). Reality exists independent of social actors and is viewed as cause-and-effect, free-context laws (Reich, 1994, p.265).

- Epistemology: Positivism focuses on characters that can be observed, measured and audited (Creswell, 2014; Easterby-Smith, Richard Thorpe, 2012). For this reason, positivists hold that feelings, opinions, and human assumptions have no value in scientific investigations.

- Axiology: Positivism is where the research is undertaken in a value-free way as far as possible. The researcher remains independent and does not have an opinion: judgment is based solely on the value of the data collected (Saunders et al., 2008).

- Methodology: Quantitative approaches are commonly used when those conducting the research hold to a philosophy of positivism. It is because positivism is based on empirical and deductive reasoning, focusing on statistical analysis and quantifiable data (Saunders et al., 2008). Qualitative studies may also qualify as concrete evidence.

In any sustainability evaluation model, selecting sustainability dimensions and indicators requires a more qualitative approach in which quantitative values are prioritised. Therefore, this research, and thus the sustainability assessment approach in the manufacturing sector and t incorporate multiple stakeholder roles, was developed based on the philosophy of positivism as it was found to be the most relevant (see Figures 3-3 & 3-4).

3.3 The current research approaches

The objectives of this study require an in-depth investigation of sustainability performance assessment. An indicator-based approach, which provides numeric values, will be used as it best represents sustainability performance criteria. An indicator is expressed by a value derived from different variables (Bragança et al., 2010)**.** The worldview selected for sustainability assessment criteria (Figure 3-2) can be divided as follows:

- Ontological: It is an external and multilayer process for determining reality; there is no human mind interference.
- Epistemological: The phenomenon studied is multi-layered and involves cognitive processing. It is about understanding the nature of inquiry and processing.
- Methodological: Mixed and multi-layered methods are employed in deductive or inductive research. It requires highlighting any wrong interpretations and shortcomings.

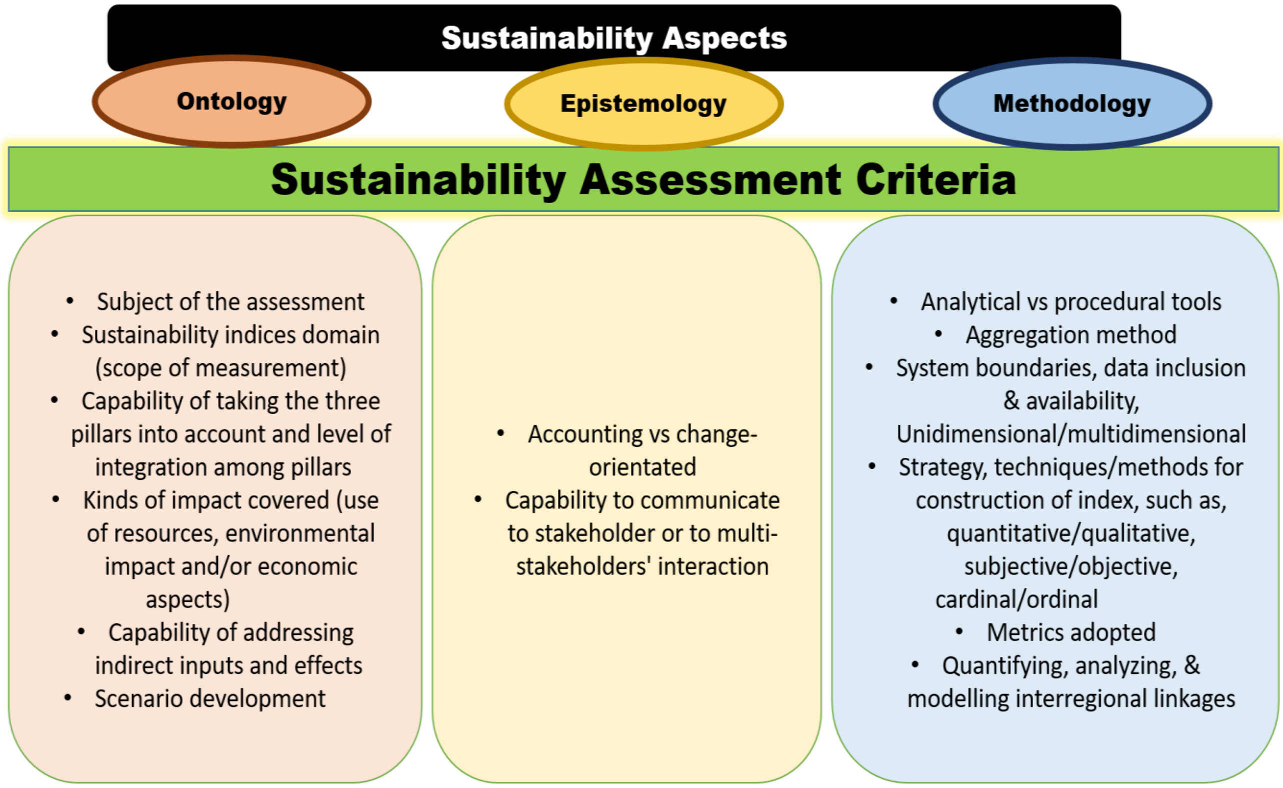

Figure 3-2 Criteria used in the review to classify sustainability assessment methodologies (adopted from Sala et al., 2015)

A systematic literature review identified gaps in current research approaches and developed an alternative assessment model that understands stakeholders' concerns. Much work was involved in the investigation and understanding of current approaches. The result is developing a unique model with features missing in current approaches; in these circumstances, the qualitative approach is appropriate and suitable.

3.3.1 Sustainability assessment procedure

The concept of sustainability must link with actions such as planning, policies, or products. Sustainability needs to be evaluated through a suitable assessment process. Figure 3-3 illustrates a conceptual framework for sustainability assessment adopted by Sala et al. (2015). It shows that a framework consists of sustainability principles and values.

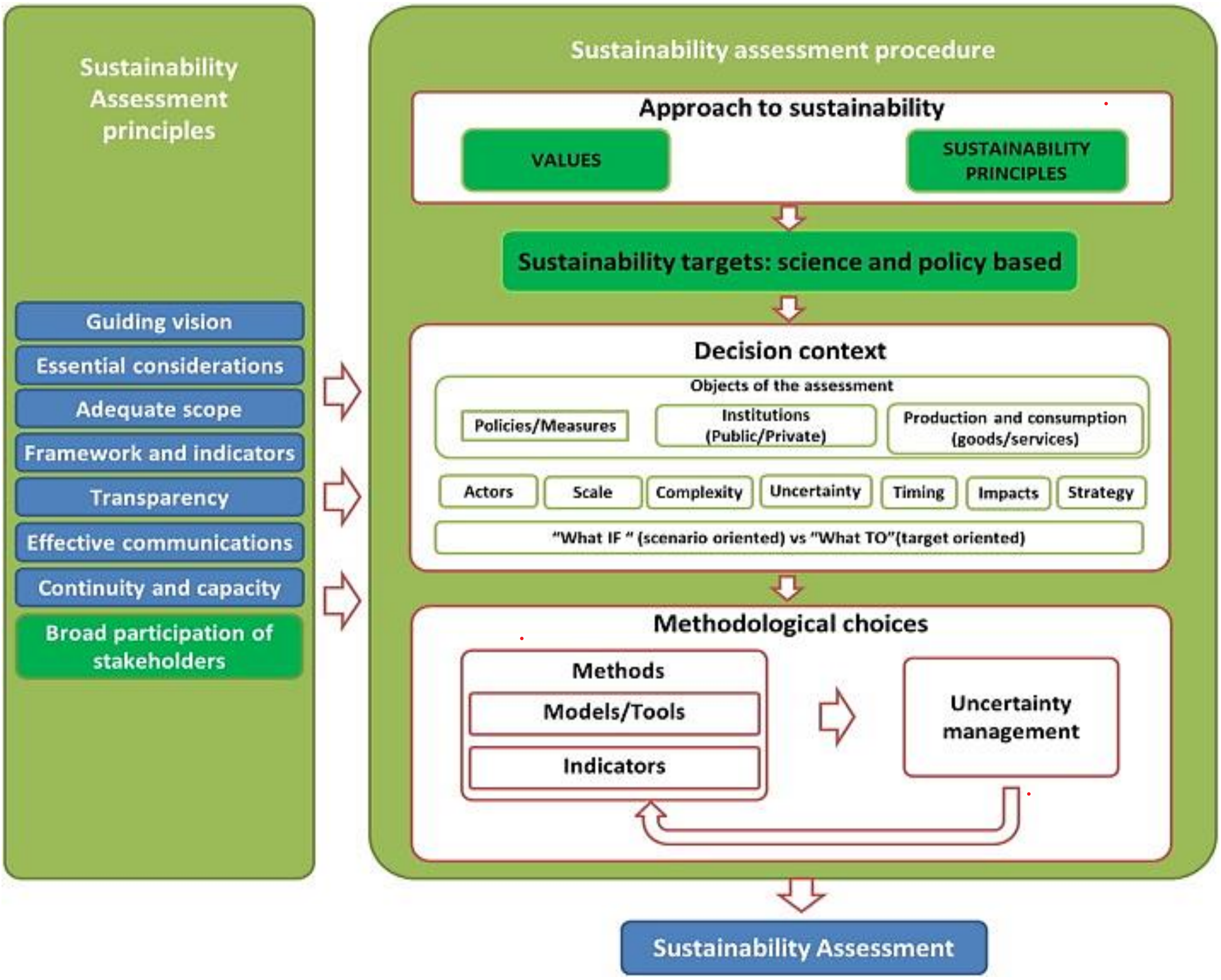

Figure 3-3 Schematic representation of the conceptual framework in sustainability assessment (Sala et al., 2015)

Figure 3-3 shows how the sustainability principle (during the project, the term 'sustainability charter' was used - Mulcahy, 2012) can help project managers or project (sustainability) teams develop strategies, decision contexts, and methodologies to complete the tasks assigned in the first place. The sustainability assessment model is driven through the sustainability principle (or charter). The primary vehicles are the decision context and choice of methodology. The same methodological approach was used to develop the proposed sustainability approach (3SM) for manufacturing.

3.3.1.1 Sustainability assessment principles

Principles are critical because they help practitioners perform a practical assessment (Sala et al., 2015). Different principles need to be taken into consideration in the assessment study. The Sala et al. (2015) model and principles were adopted to develop the sustainability approach. They are described as follows:

- Guiding Vision: Sustainable development means fulfilling existing production and consumer requirements without compromising future generations' needs.

- Essential considerations: Social, environmental, and economic components should consider any development. Performance management and R&D dimensions are equally important as without having R&D involvement, manufacturing practices could become outdated and produce high emissions. Performance management needs to emphasise that resources are utilised to maximum effect.

- Adequate scope: The progress toward sustainable development should address both short and long-term effects of current policies and industrial practices. It should adopt a reasonable timeline and geographical scope to study local and global effects.

- Framework and indicators: For a conceptual framework, core indicators and associated data are identified, and models and projections are necessary to infer trends and build scenarios.

- Transparency: The transparency of data, indicators, models, results and accessibility to findings is vital.

- Effective communication: Sustainability assessment requires clear and primary language to guarantee effective communication and attract the audience. Results should be presented in a rational and unbiased way.

- Continuity and capacity: Sustainability assessment requires continuous monitoring through repeated measurements.

- Multiple stakeholders: A specific requirement of sustainability assessment is the stakeholders' involvement. Sustainability assessment should find appropriate ways to strengthen the role of stakeholders in policymaking. The application of the principles set out in Section 3.3.1.1 above and outlined in Sala's (2015) model in
- Figure 3-3 was used during the sustainability assessment approach (3SM) development and will be discussed in Chapters 4 and 5 during the development and validation phase.

3.4 Research structure and layout

Currently, different approaches are employed for sustainability performance assessment. In this project, a modified, QFD-based method was developed. It bridges the gaps between the manufacturers' and stakeholders' expectations in the literature review. After generating the sustainability approach, the approach was presented to some in the manufacturing sector, and subsequent feedback focused on the applicability, utility, and relevance to the manufacturing industry. After constructive criticism from academic researchers and industry practitioners, the proposed sustainability approach underwent further development.

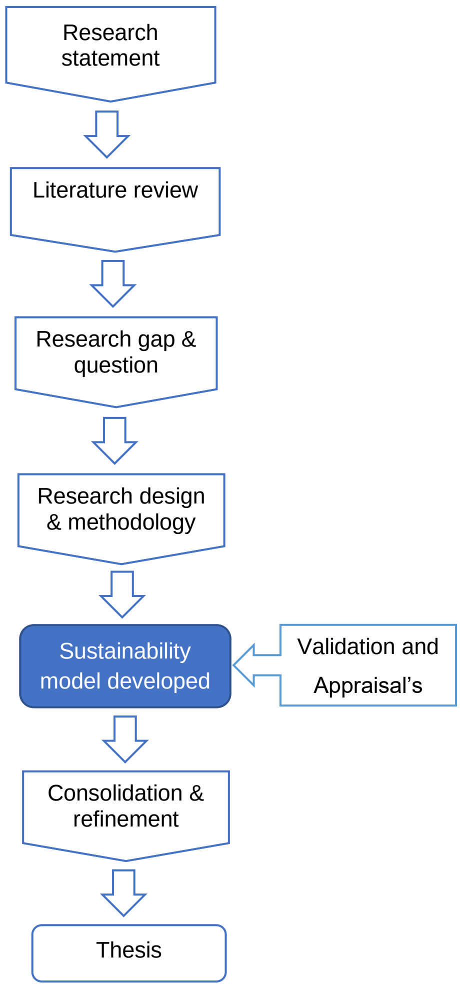

Figure 3-4 Research layout for a sustainability approach development

The validation of the sustainability approach developed was completed in two phases. First, the approach was presented to selected academic researchers who formed a sustainability team. This team surveyed, collected, and prioritised data from university academic researchers and collected consumer expectations through a survey. The details of validation and participation will discuss in chapters 4 & 5. The sustainability approach was further enhanced and upgraded based on Version I, II, III & IV feedback.

This approach assumes that stakeholders are the central drivers of the evaluation and assessment in its design. Satisfying their sustainability evaluation desires is the priority; manufacturers' efforts must consider their vital interests. Figures 4-2 outline the sustainability approach developed for manufacturing and the two phases. The first phase is sustainability approach development. The second phase has sustainability approach validation, including the pilot study and full validation in manufacturing organisations using manufacturing data. The validation and appraisals of the sustainability approach assure its relevance and suitability in the manufacturing sector.

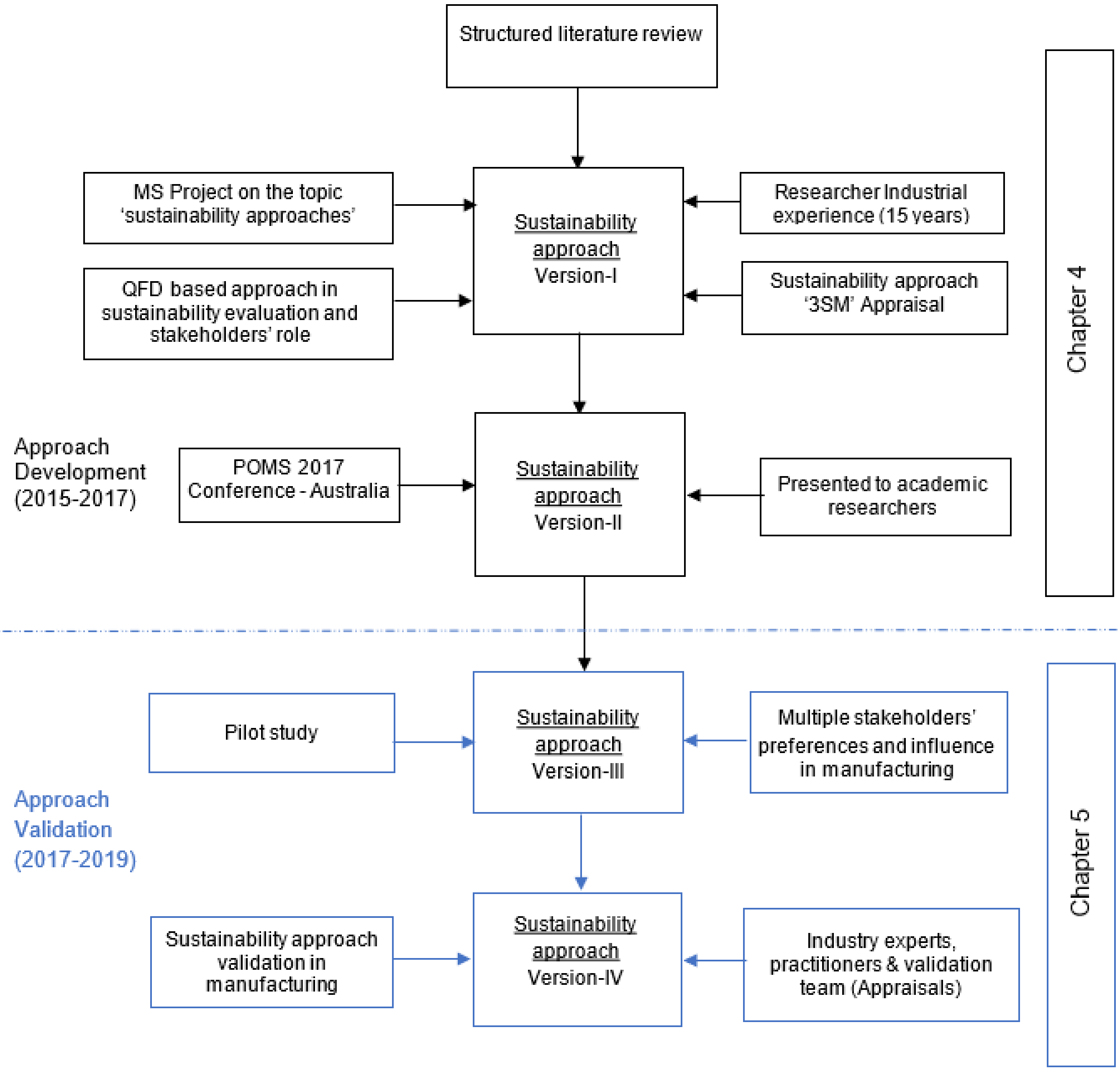

Figure 3-5 Sustainability assessment tool development and validation

The sustainability approach evaluation and versions (I, II, III, IV) developed in Figures 3-5 are explained in Figure 3-6 and show the sustainability approach's development, including changes made through appraisals, pilot study, and validation in a manufacturing organisation. More details about the sustainability approach evolution discussed in Chapter 4 presented the steps involved and appraisal of the sustainability approach.

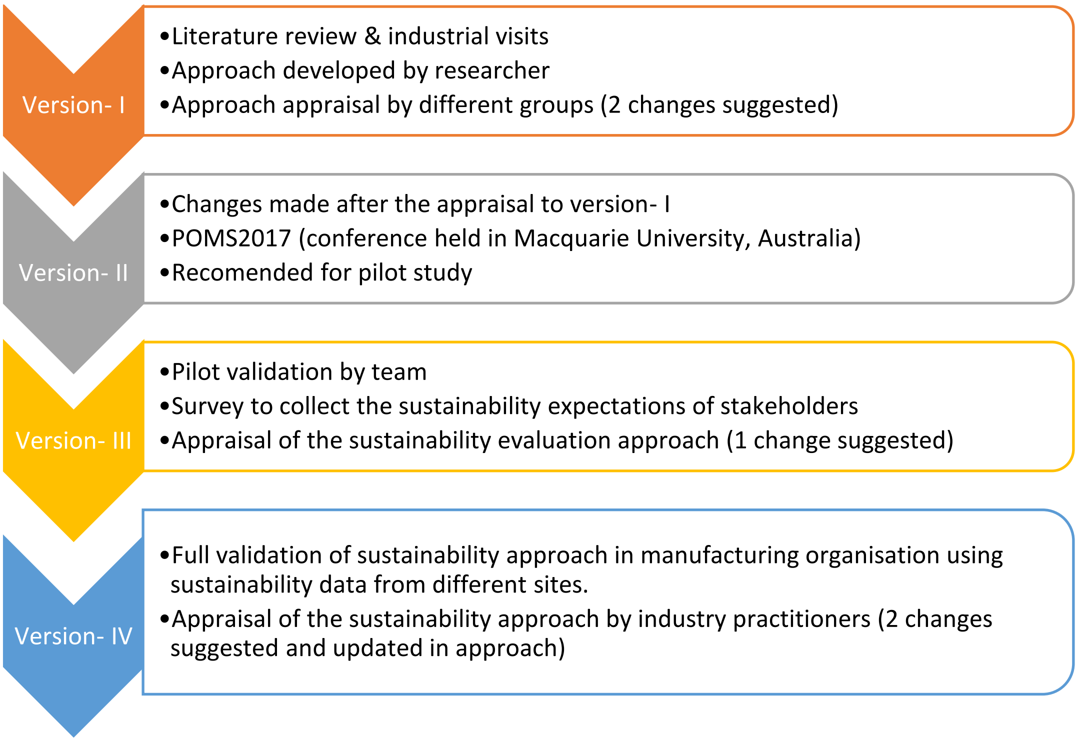

Figure 3-6 Overview of the sustainability approach versions

Figure 3-6 shows the 3SM sustainability approach versions developed and updated after the different appraisals with technical groups and experts on the topic. The sustainability approach presented changed from Version -I to Version –IV after the feedback at different stages to gather the knowledge and industry experts' opinions—further how changes have also been highlighted and explained. Sustainability approach versions will be briefly discussed in the following sections.

3.5 Chapter summary

This chapter explained the methodology and path adopted to develop a sustainability approach and validation process in a manufacturing organisation using sustainability data and refinement of the approach through various expert appraisals. It also explained the research methodology adopted to develop a sustainability approach for manufacturing and different versions. The assessment approach evolved through the pilot and full validation process and was updated through experts' feedback. In the following, Chapters 4 & 5 explain the full details of the validation criteria and method adopted.

Chapter 4 Sustainability assessment approach in manufacturing

Various studies, surveys, and literature indicate that organisations are under increasing pressure from multiple stakeholders to improve sustainability performance in the supply chain (L.-A. Ho, 2011; Tuni & Rentizelas, 2018). “Sustainability assessment is a tool that can help decision-makers and policymakers determine what actions they should take and should not take to make society more sustainable” (Devuyst, 2001, p.9). Most of the current sustainability assessment approaches available in the literature or practice – including Global Reporting Initiatives (GRI) – are generic and are used across all sectors and do not fully account for the multiple stakeholders' preferences in sustainability prioritisations (GRI, 2018; Jayal et al., 2010; Swartz, 2016). The subsequent gap between multiple stakeholders’ preferences and manufacturers’ actions generates the need for a new sustainability approach to bridge that gap.

This chapter outlines an improved sustainability assessment approach to measure multiple stakeholders’ prioritisations in the manufacturing sector. This approach provides a conceptual framework and an indicator-based approach to measuring, recording, and managing sustainability performance (BSI, 2012; Young & Solomon, 2009). This chapter includes the background and novel the sustainability approach developed, and different versions evolved through feedback and critical appraisal.

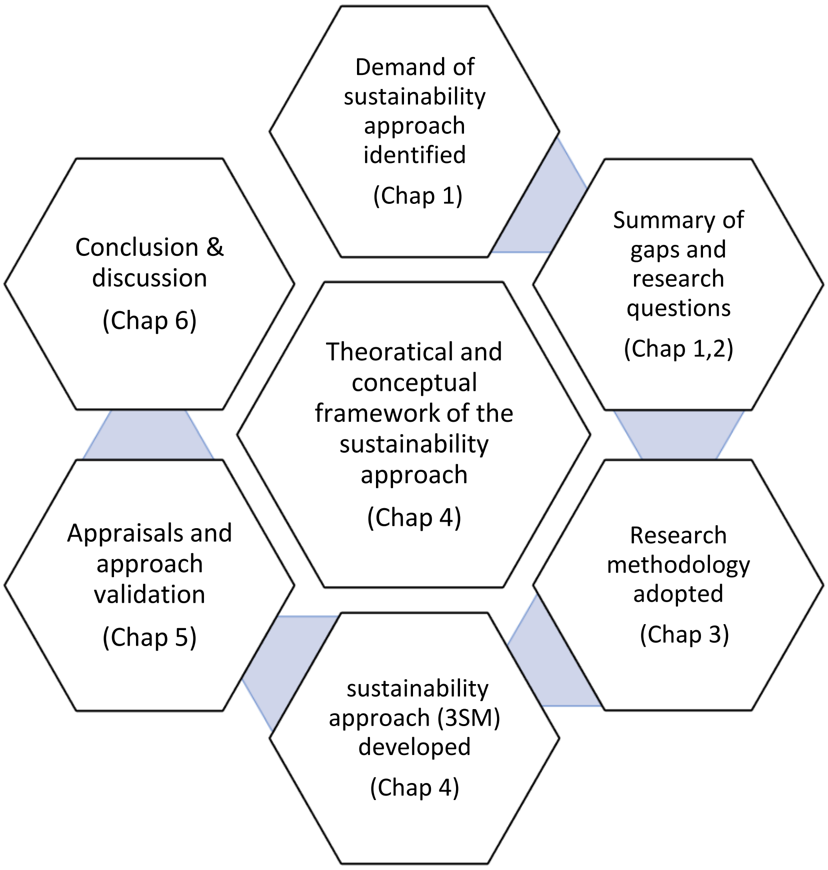

Figure 4-1 Sustainability approach development and appraisal in manufacturing

Figure 4-1 shows an outline and background of the methodology adopted to develop the sustainability approach (3SM) and validation. After defining sustainability, the next task is to define its objective, select appropriate system boundaries in the supply chain, then select sustainability parameters, track progress, and set targets for successfully measuring sustainability in manufacturing (Hay, 2015; Mulcahy, 2012; Romli, 2015; Veleva et al., 2001). It further builds a sustainability score system for elements that can understand manufacturing operations and the supply chain requirements. This score-based approach may help manufacturers and decision-makers prioritise actions to improve sustainability performance. The features of the approach, development phases, a conceptual explanation, and steps involved in performing sustainability assessments in manufacturing are discussed in this chapter.

4.1 A framework of the sustainability assessment approach in manufacturing

This section outlines the description, justification, and structure of the sustainability approach developed and discusses how it works, pre-requisites, including the sustainability data and multiple stakeholders' prioritisations. The four-step sustainability assessment framework outlined in Table 4-1 provides the logical order of doing project adopted methodology (Boulanger, 2008; Mulcahy, 2012; Permatasari, 2006) four steps of the manufacturing's sustainability scoring system. The four steps framework explains the information process flow from one step to the next. These steps include a sustainability charter, selecting a cross-functional team in the organisation who may name a sustainability team, selecting manufacturing boundaries (system boundaries), and sustainability indicators representing SE (sustainability elements).

Table 4-1 Four steps framework of carrying the sustainability approach

A coceptual framework of 'Sustainability score system in manufacturing' (3SM)			
	Description	Tools	
Plan	Sustainability charter Sustainability team System boundaries	Delphi techniques Group discussion	Step-I
Integrate & Measure	Sustainability pillars & elements selection Multiple stakeholders role Manufacturing functions	Delphi techniques Surveys Pairwise relationship QFD modified tool	Step-II
Measure & Control	Sustainability indicators selection Sustainability targets	Group discussion pairwise relationship & AHP Normalisation method	Step-III
Organise	Sustainability reporting	CSR's GRI guidelines	Step-IV

Table 4-1 outlines the concept and outline of the sustainability approach framework developed for manufacturing. Its purpose is to ascertain stakeholders and manufacturer aspirations regarding sustainability performance and integrate them into manufacturing sustainability targets and goals. It is an overview of how the sustainability framework guides stakeholders' expectations alongside relevant information in the team's manufacturing process to score the sustainability performance. Steps – II & III are the most important, prioritising sustainability elements, identifying hotspots, and evaluating the sustainability score.

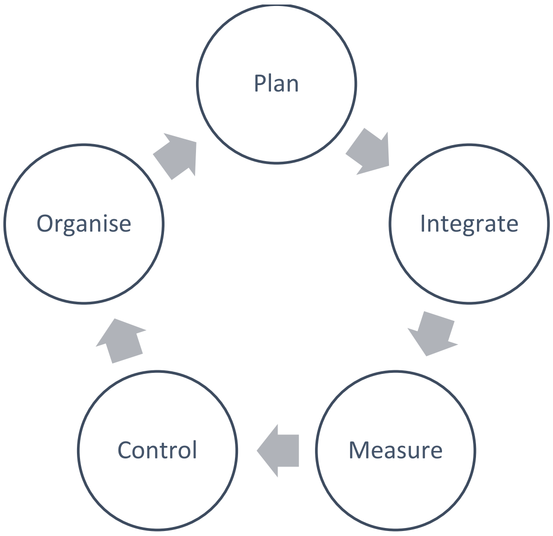

Figure 4-2 Balance scorecard-based performance measurement approach adopted from (Permatasari, 2006)

The framework was developed based on the researcher's experience managing sustainability issues in manufacturing over the past 16 years. This includes collecting, managing and reporting sustainability data for the corporate social responsibility reporting in SMEs and multinationals. This further investigation of the approaches practised in published literature and industry; the framework also accounted for the discussion made by Permatasari (2006) and Boulanger (2008) on converting a conceptual model into an indicators-based approach (Singh et al., 2012). The framework and approach follow the sustainability charter's development, selecting the system boundaries identified in the literature review, and consolidating various industry standards, targets and organisation ambitions (BSI, 2012; Mulcahy, 2012). The approach also guides on why and how to select sustainability pillars (out of five pillars) Nist (2015), SE selection from Global reporting initiative standards by GRI (2018) as it is now industry-wide practices. It is also emphasised that the most effective way for sustainability evaluation in manufacturing is to link the sustainability process and operations to indicators (provided an indicators data bank for sustainable manufacturing). Then, by controlling indicators, manufacturing performance will help manage sustainability (Oecd, 2008, 2009, Singh et al., 2012) in the manufacturing sector.

The framework is designed to allow an organisation to integrate all the sustainability-related systems and initiatives to merge in the same framework (BSI, 2012; Springer et al., 2016b; Wiek et al., 2011) through the sustainability team and Delphi technique to use SE and indicators selection in manufacturing. This is a bottom-upward approach (Pope et al., 2004), which involves relevant people making decisions about manufacturing sustainability targets. The sustainability framework was developed regarding the above discussion, considering the shortcomings and gaps identified in current approaches. The framework's basis focuses on how a conceptual approach shall link to a qualitative subject, which can further be transformed into measurable parameters defined with legitimate criteria to record those manufacturing parameters.

Boulanger (2008) also informed the aim of quantifying qualitative data by splitting sustainability assessment into secondary and tertiary levels and then into measurable sustainability indicators, which is the key basis of the sustainability framework outlined in Table 4-1. The summary of the gaps identified in the literature review regarding sustainability assessment approaches and practices, especially the lack of multiple stakeholders' preferences in consideration, is incorporated into the framework. An innovative method of gauging multiple stakeholders' impact will capture the preferences and influence in manufacturing and use them to inform the manufacturer of what to do and where to allocate resources. For this, a modified QFD approach was adopted. It works well to prioritise the relationships among different SE and their subsequent reinforcement of other sustainability indicators (Osiro et al., 2018; Romli, 2015; Springer et al., 2016b; Warwick, 2007). Some other tools with effects, such as pairwise relationships and normalisation methods, were used in some steps and provided justification and benefits later in the chapter.

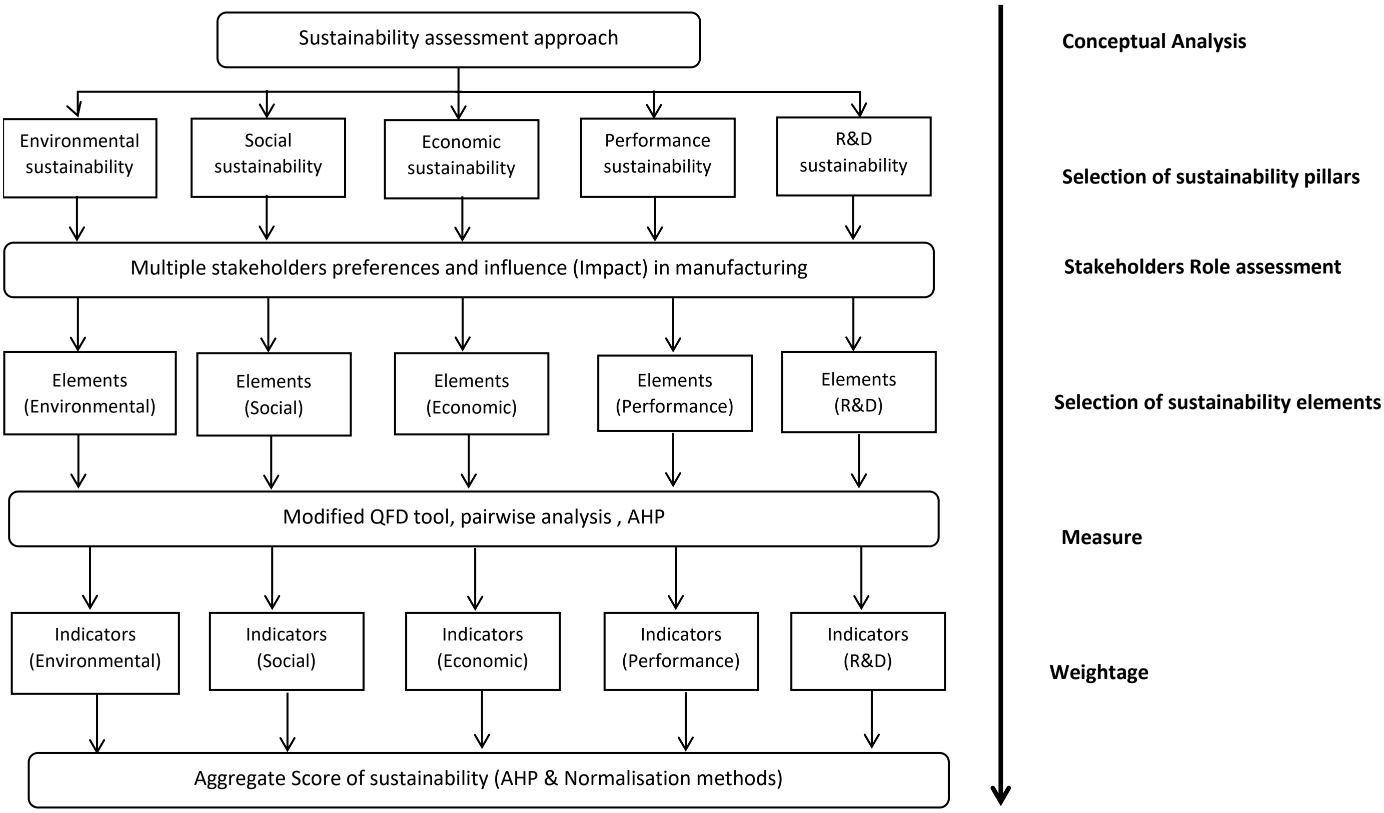

Figure 4-3 Objective tree showing the steps involved in sustainability evaluation modified and adopted by Boulanger (2008) & Oecd (2008,2009)

Figure 4-3 outlines the steps involved in developing the sustainability concept in manufacturing, selecting SE, multiple stakeholders' priorities, and sustainability indicators and assessing each indicator's contribution to manufacturing. More details about the structure and assessment approaches are discussed in the following sections.

The four steps sustainability approach, framework and steps are appraised by sustainability practitioners and validated using actual sustainability data

4.1.1 Sustainability approach at step – I

The first step includes a formal write-up of a sustainability charter by senior management, including an outline of objectives. This charter will explain the sustainability assessment purposes, the context of assessment within the organisation and system boundaries in manufacturing. It includes the organisations' ambitions to be responsible producers of goods while benefitting from natural resources and resource allocation to assess sustainability

(Mulcahy, 2012). The sustainability charter will guide the cross-functional sustainability team (made up of employees based on sustainability and manufacturing).

The sustainability charter should identify and authorise a sustainability team in an organisation responsible for evaluating sustainability and reporting. The sustainability team shall further lead the sustainability assessment and define the charter. Furthermore, the team is accountable for seeking expert advice when necessary, using the Delphi technique. Additionally, the sustainability team's responsibility is to extract measurable objectives and deliverables from the sustainability charter, highlight the sustainability drivers (such as legislative and compliance aspirations), and refer to multiple relevant stakeholders in the supply chain. The sustainability team then identifies system boundaries in the manufacturing context, sustainability dimensions, elements, and indicators. It also identifies the resources required for sustainability evaluation in the organisation. The sustainability charter at step-I also highlights sustainability dimensions such as the environment, the economy, social factors, R & D, and performance, which senior management should consider while drawing up the sustainability charter.

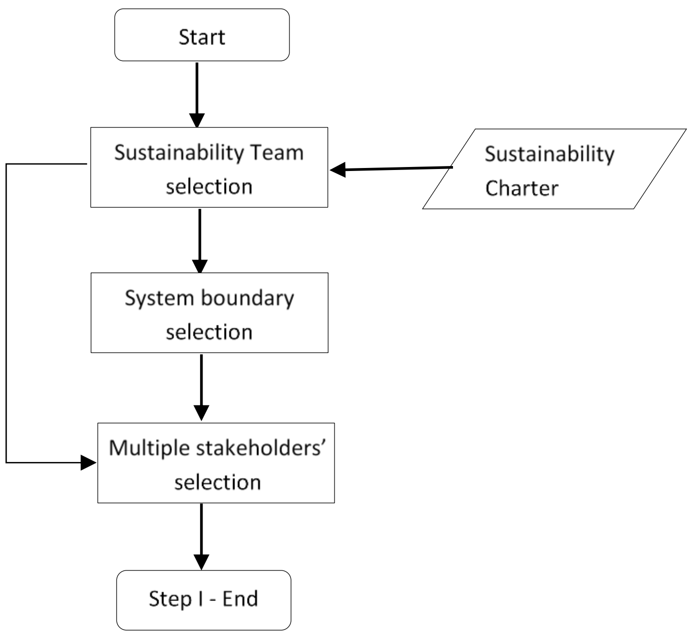

Figure 4-4 Sustainability assessment approach developed at step – I

Each step of the framework of how it processes the information is explained in an orderly way. Figure 4-4 shows the sequential flow of information at step-I, beginning with selecting a sustainability team identified in the sustainability charter and system boundaries in manufacturing sustainability evaluation. The five system boundaries are identified, and preferences were outlined in the literature review (chapter 2). The sustainability team should also investigate the multiple stakeholders' roles in a supply chain that holds interest and influence in sustainable manufacturing. Multiple internal and external stakeholders have an interest or preference and influence their sustainability performance. As discussed in the literature review, it includes the customers and consumers. The internal stakeholders, including the organisation's employees, have influence and direct involvement in manufacturing functions and decision-making. The external stakeholders, including consumers and end-users, NGOs, local and international legislative authorities, the manufacturing sector, contractors, suppliers, and groups of people, have expectations and influence manufacturing.

The information in step-I included the sustainability charter, which further helps select the sustainability team, appropriate system boundaries in sustainability assessment and performance, and identify the multiple stakeholders to account for while prioritising sustainability pillars, elements, indicators, and performance.

4.1.2 Sustainability approach at step – II

The information gathered by the sustainability team in step-I, such as the list of multiple stakeholders and system boundary selection, was used to measure sustainability in manufacturing in step II. In step II, the sustainability team identifies sustainability pillars out of five (NIST, 2015) and their representation with SE in manufacturing. The sustainability team understands the manufacturing operations and SE involved. The team then assesses the sustainability pillars' hierarchy and elements in conjunction with multiple stakeholders' preferences and influence in manufacturing. A QFD modified matrix will also be used to prioritise the manufacturing function to identify hotspots, assign resources, and manage them in the organisation's best interest to satisfy multiple stakeholders. This assessment will provide high-performing SE and manufacturing functions in the organisation.

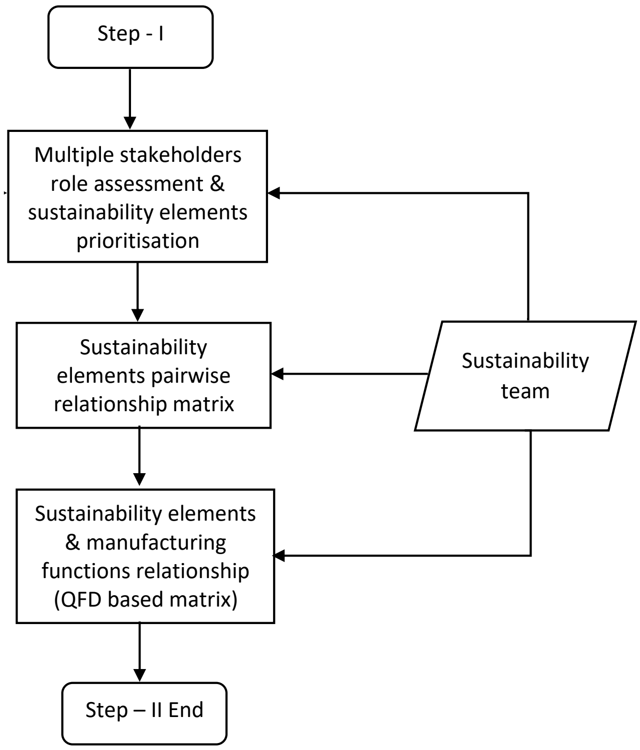

Figure 4-5 Sustainability assessment approach developed at step – II

Figure 4-5 outlines the process of information flow and the sustainability team's selection of the sustainability pillars, elements, and system boundaries. The sustainability team shall survey multiple stakeholders (internal and external) relevant to the organisation to use their aspirations to rank the selected sustainability pillars listed by Nist (2015) and SE listed in the database of GRI (2018). It is well-known that various business stakeholders have varying expectations and influence over the organisation (Jayal et al., 2010). So it is important to value their contribution to sustainability prioritisation in manufacturing.

Stakeholders role assessment in manufacturing			External stakeholders expectations		E(X) - Average of external stakeholders expectations	E (I) - External stakeholders Influence	**External stakeholders Impact = E(X) x E(I) = ESI**	Internal stakeholders expectations		I(X) - Average of internal stakeholders expectations	I (I) - Internal stakeholders Influence	**Internal stakeholders Impact = I(X) x I(I) = ISI**
Primary level	Sustainability pillars	Tertiary level - Sustainability elements (SE j)	1	2				1	2			
Sustainability score system in manufacturing	Environment	Sustainability element 1										
		Sustainability element 2										
		Sustainability element 3										
	Social	Sustainability element 4										
		Sustainability element 5										
	Economic	Sustainability element 6										
		Sustainability element 7										
	Tech	Sustainability element 8										
		Sustainability element 9										
	PM	Sustainability element 10										
		Sustainability element 11										

Figure 4-6 Internal & external stakeholders role impact (expectations * influence) in manufacturing

Abbreviated	
SE	*Sustainability elements in manufacturing*
E(X)	*Average of external stakeholders expectations in manufacturing*
E(I)	*Average of internal stakeholders influence in manufacturing*
ESI	*External stakeholders impact, ESI= E(X)xE(I)*
I(X)	*Average of internal stakeholders expectations in manufacturing*
I(I)	*Average of internal stakeholders influence in manufacturing*
ISI	*Internal stakeholders impact, ISI= I(X)xI(I)*
Tech	*Research and development (sustainability pillar)*
PM	*Performance management*

The matrix shown in Figure 4-6 lists the five sustainability pillars with different subsets of SE in manufacturing. SEi and SEj are sustainability elements listed horizontally and vertically to develop the relationship. After selecting the SE, the sustainability team shall survey multiple stakeholders (internal and external stakeholders) to understand their preferences. The sample survey form used to collate multiple stakeholders' prioritisations is added in the appendix. The matrix shown in Figure 4-6 considers two internal and two external stakeholders, but the sustainability team should decide how many internal and external stakeholders to survey.

Figure 4-6 shows two columns for sustainability expectations and the influence of SE. The survey form suggests rating stakeholders' expectations on a scale of 1 to 5, where 5 indicates the maximum rating for that sustainability factor, and 1 indicates the minimum weighting. The stakeholder's expectations average multiply with the influence of stakeholders considering all internal and external stakeholders have the same influence on the supply chain. However, sustainability can decide where external stakeholders have different expectations and influence in the business; each stakeholder impact shall calculate and rate the sustainability elements. In most organisations, all internal stakeholders can have the same influence; however, varying sustainability expectations. This scale rating gives a more accurate hierarchy of SE, considering multiple stakeholders' preferences and influences. The sustainability team should discuss and assess different stakeholders' influence and rate them according to their expectations and influence to gauge SE's impact. The impact is calculated by multiplying stakeholders' preferences by their influence on manufacturing. These calculations are explained and justified in the literature review.

The external stakeholders' impact (ESI) and internal stakeholders' impact (ISI), assessed in the matrix shown in Figure 4-6, provide the SE's weightage in the eyes of multiple stakeholders and will be used in the following matrix to determine pairwise relationships. All internal stakeholders considered the exact value of influence in the supply chain's manufacturing (functional heads). In contrast, external stakeholders have varied influences in business, so the individual should assed. These matrices are interlinked, and their data are used to achieve meaningful information for the manufacturer.

Pairwise relationships	PR
Strong	●
Moderate	○
Weak	▽

Column #					1	2	3	4	5	6	7	8	9	10	11
Relationship Matrix					Pairwise relationship /comparison among sustainability										
Strategic Requirements			**ISI**	**ESI**	Sustainability elements (SE i)										
					Environment			**Social**		**Economic**		**TECH**		**PM**	
Primary level	**Sustainability pillars**	Tertiary level - Sustainability elements (SE j)	Internal Stakeholders Impact	External Stakeholders Impact	Sustainability element 1	Sustainability element 2	Sustainability element 3	Sustainability element 4	Sustainability element 5	Sustainability element 6	Sustainability element 7	Sustainability element 8	Sustainability element 9	Sustainability element 10	Sustainability element 11
Sustainability score system in Manufacturing	Environment	Sustainability element 1	1	1	●										
		Sustainability element 2	1	1		●									
		Sustainability element 3	1	1			●								
	Social	Sustainability element 4	1	1				●							
		Sustainability element 5	1	1					●						
	Economic	Sustainability element 6	1	1						●					
		Sustainability element 7	1	1							●				
	Tech	Sustainability element 8	1	1								●			
		Sustainability element 9	1	1									●		
	PM	Sustainability element 10	1	1										●	
		Sustainability element 11	1	1											●
Pairwise relationship		Pairwise elements relationship score (PR -E)			909	909	909	909	909	909	909	909	909	909	909
		Relative percentage score			9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%
		Weight chart													

Figure 4-7 Sustainability elements prioritisation by having a pairwise relationship

Figure 4-7 shows the pairwise relationship matrix of SE developed by the sustainability team using their operational knowledge and the Delphi technique. Figure 4-7 shows ESI and ISI scores of 1 for each sustainability element. At the same time, comparing the sustainability elements in matrices, the comparison was made from rows to columns. The team leader should develop a consensus on a strong, weak or no relationship score among the sustainability elements.

In a conflict situation, use the Delphi technique or accept more team members to vote for a decision.
These scores should be replaced with the scores calculated from Figure 4-6. The sustainability team should decide the relationship between SE in the matrix. The pairwise relationship among SE is shown using the following signs: ● = 9, ○= 3, ▽= 1, and no relation value = 0.

Internal and external sustainability stakeholders' preferences prioritise the SE and complete a pairwise relationship. The SE in Figure 4-7 are listed horizontally (SEi) and vertically (SE j) in a pairwise relationship. The pairwise relationship provides the rank of key SE in manufacturing. The sustainability ranking will help manufacturers and decision-makers to focus their attention and resources accordingly.

The following formula calculates the pairwise relationship score:

$$PR - Ei = \sum_{j=1}^{n} \left[\left(SE_{ij} \right) . ISI + \left(SE_{ij} \right) . ESI \right] i = (1, \dots, n)$$

And with a further simplified form:

$$PR - Ei = \sum_{j=1}^{n} \left[\left(SE_{ij} \right) . (ISI + ESI) \right] i = (1, \dots, n)$$

EQUATION 4-1

Where $PR - E$ is about the pairwise relationship among SE considering internal and external stakeholders' impact, symbol '$\in{}'$ represents the pairwise relation between SE *I*, the SE in rows, and 'The SE *J*, the SE in columns (as shown in Figure 4-7). Where i & $j = 1$ (starts from 1) and 'm' and 'n' are the total number of SE in rows and columns, respectively (selected by the sustainability team).

Figure 4-7 also provides the key SE that impacts manufacturing. The sustainability team will input these figures into Figure 4-8 to complete SE's relationship with the manufacturing function. The pairwise relationship score, as a percentage, will be used in the following QFD modified matrix to prioritise manufacturing functions in manufacturing.

Pairwise relationships	PR
Strong	●
Moderate	○
Weak	▽

			Column #		1	2	3	4	5	6	7	8	9	10	11
			Relationship Matrix		Manufacturing Functions in Supply chain										
	QFD modified Matrix			**Pairwise relationship score (PR-E) in %**	**MF i**										
	Primary level	**Sustainability pillars**	Tertiary level - Sustainability elements (SE j)		Manufacturing Function 1	Manufacturing Function 2	Manufacturing Function 3	Manufacturing Function 4	Manufacturing Function 5	Manufacturing Function 6	Manufacturing Function 7	Manufacturing Function 8	Manufacturing Function 9	Manufacturing Function 10	Manufacturing Function 11
1	Sustainability score system in Manufacturing	Environment	Sustainability element 1	9%	○										
2			Sustainability element 2	9%		○									
3			Sustainability element 3	9%			○								
4		Social	Sustainability element 4	9%				○							
5			Sustainability element 5	9%					○						
6		Economic	Sustainability element 6	9%						○					
7			Sustainability element 7	9%							○				
8		Tech	Sustainability element 8	9%								○			
9			Sustainability element 9	9%									○		
10		PM	Sustainability element 10	9%										○	
11			Sustainability element 11	9%											○
	MF relative contribution 'RW'		Manufacturing functions weightage (RW)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
			Manufacturing functions rating (RW)	%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%
			Weight chart - MF												

Figure 4-8 Weighting of different manufacturing functions in sustainability performance

The matrix's manufacturing functions include Engineering, Production, Marketing Procurement, etc. The matrix in Figure 4-8 shows the relationship between SE and manufacturing functions within the organisation and the prioritisation of the manufacturing functions that significantly impact sustainability. This matrix is based on the QFD tool to prioritise manufacturing functions to understand the hotspots in manufacturing. Here, the multiple stakeholders' prioritisations and influence in manufacturing contribute to identifying hotspots in manufacturing functions.

The matrix identifies the hotspots and manufacturing functions with higher manufacturing and sustainability roles by accounting for multiple stakeholders' impacts. The relative weight of MF is calculated in the following mathematical equations:

$$RW = \sum_{j=1}^{n} \left[\left(MF_{ij} \,.\, SE_{ij} \right) x \; (PR - E) \right], i = (1, \dots, n)$$

Equation 4-2

The symbol '∈ ′ represents the pairwise relation between 'SE' and 'MF'. Also, i & $j = 1$ (starts from 1) and 'n' are the total numbers of SE and MF in the list. The hot spots identification in Figure 4-8 identifies key manufacturing functions influencing sustainability. The percentage shows the role of each SE in manufacturing. This percentage score enables manufacturers and decision-makers to take informed action and initiative for sustainability performance. The output of the calculations performed in step - II will be used to step - III.

4.1.3 Sustainability approach at step – III

In step - III of the approach, SE is further split into sustainability indicators represented in manufacturing. The benefits of using an indicator-based methodology for representing sustainability in manufacturing operations were discussed in the literature review (chapter 2). A sustainability indicators data bank formulated for sustainable manufacturing was collected from the most published and available indicators in the appendix. The sustainability team, who has a functional knowledge of manufacturing and supply chains, can select appropriate sustainability indicators representing SE and manufacturing.

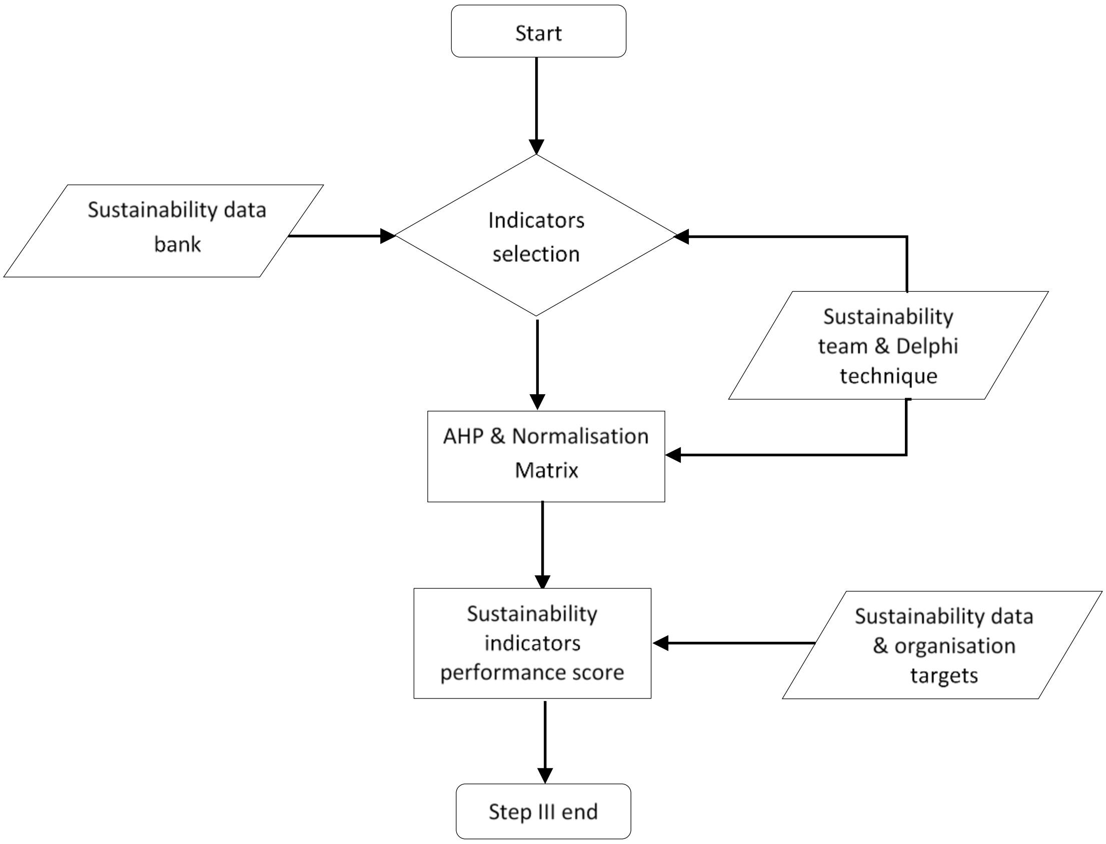

Figure 4-9 Sustainability evaluation approach at step - III

Figure 4-9 outlines the steps in selecting sustainability indicators and sustainability in manufacturing. Cross-functional knowledge of manufacturing operations can help use a Delphi technique to select the most relevant manufacturing indicators. The Delphi method is a forecasting approach based on the results of multiple rounds of questionnaires sent to a group of experts. The selection of indicators must be represented in manufacturing operations, manufacturing sector priorities and interests, stakeholders' expectations, legal obligations, and international and local sustainability trends regarding manufacturing expectations (Mangili et al., 2019; Oecd, 2008, 2016).

Following this, the sustainability team prioritise indicators using the Analytic hierarchy process (AHP) technique, which allows them to understand the most important ones in manufacturing. The matrix shown in Figure 4-10 explains the SE selected by the sustainability team and the relationships between them using multi-criteria decision-making (MCDM) and normalisation approaches in evaluating indicators within the organisation (Boulanger, 2008; Oecd, 2009; Permatasari, 2006).

Sustainability indicators role accounting stakeholders role

Relationships
1= the row is equally important as the column
3= slightly more important
5= more important
7= much more important
9= very much more important
0.33 = slightly less important
0.20 = less important
0.14 much less important
0.11 = very much less important

		Indicators from Data Bank		Indicator 1	Indicator 2	Indicator 3	Indicator 4	Indicator 5	Indicator 6	Indicator 7	Indicator 8	Indicator 9	Indicator 10	Indicator 11	Indicator 12	Indicator 13	Indicator 14	Indicator 15	Indicator 16	Indicator 17	Indicator 18	Indicator 19
Elements representing the status of sustainability	Environment	Sustainability element 1	Indicator 1	1																		
			Indicator 2		1																	
			Indicator 3			1																
		Sustainability element 2	Indicator 4				1															
			Indicator 5					1														
		Sustainability element 3	Indicator 6						1													
			Indicator 7							1												
	Social	Sustainability element 4	Indicator 8								1											
			Indicator 9									1										
		Sustainability element 5	Indicator 10										1									
			Indicator 11											1								
	Economic	Sustainability element 6	Indicator 12												1							
			Indicator 13													1						
		Sustainability element 7	Indicator 14														1					
			Indicator 15															1				
	Tech	Sustainability element 8	Indicator 16																1			
		Sustainability element 9	Indicator 17																	1		
	PM	Sustainability element 10	Indicator 18																		1	
		Sustainability element 11	Indicator 19																			1
	Total			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Indicator	Normalised Assessment																			Absolute Weigh	Elements relationship score in %	Relative function AHP Priority (%)
Indicator 1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	9%	3%
Indicator 2	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1		3%
Indicator 3	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1		3%
Indicator 4	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	9%	5%
Indicator 5	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1		5%
Indicator 6	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	9%	5%
Indicator 7	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1		5%
Indicator 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	9%	5%
Indicator 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1		5%
Indicator 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	9%	5%
Indicator 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1		5%
Indicator 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	9%	5%
Indicator 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1		5%
Indicator 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1	9%	5%
Indicator 15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1		5%
Indicator 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1	9%	9%
Indicator 17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1	9%	9%
Indicator 18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1	9%	9%
Indicator 19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1	9%	9%
Total	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19	100%	100%

Figure 4-10 Sustainability indicators' role in performance accounting for multiple stakeholders' roles

The matrix in Figure 4-10 shows the sustainability pillars and elements further split into sustainability indicators representation and their pairwise relationship and normalisation in manufacturing. SE selected from the GRI 4.0 aspect register (GRI, 2018) are split further into measurable indicators selected from the sustainability indicators databank listed in the appendix. The indicators are quantitative measures of sustainability elements represented in the supply chain. Figure 4-10 also shows MCDM and normalisation techniques to assess the contribution and role of sustainability indicators in manufacturing (Camarinha-Matos et al., 2016). The MCDM method weights each sustainability indicator and uses the same methodology employed by the European Commission (Benini et al., 2014) to evaluate environmental footprints. An in-process case study also uses it to prioritise indicators (Camarinha-Matos et al., 2016).

AHP, MCDM, and normalisation approaches are successful techniques for prioritising indicators in a given set (Mu & Pereyra-Rojas, 2017). They also analyse how different indicators affect each element's net contribution and weight in the assessment. The normalisation approach shows how each indicator and element plays a role in manufacturing. It is based on the understanding that each indicator has a different function and contribution. Sustainability indicators also create a ripple effect on performance and reinforce sustainability indicators. For instance, emissions and energy consumption have a strong relationship, as many emissions come from energy use (Camarinha-matos & Falcão, 2016; Mu & Pereyra-Rojas, 2017).

The matrix aims to prioritise the most critical sustainability indicators in manufacturing. AHP uses a pairwise approach to evaluate SE's impact; the normalisation method's matrix is the first step in the decision-making process and involves averaging the various weights into other indicators. It is helpful for comparison purposes (Camarinha-Matos et al., 2016). Figure 4-10 shows the normalisation technique N1 (linear: max) combined with N3 (linear-sum) to ensure the sum is ‘1.’

The indicators’ contribution assessment was then used to establish each indicator's value by understanding and accounting for multiple stakeholders using pairwise relationships and QFD-based methodology to rank manufacturing indicators. The sustainability indicators’ values in manufacturing and targets can then be set. The assessment also indicates how each sustainability indicator contributes to sustainability in manufacturing. The SE and indicators with performance scores are listed in the matrix shown in Figure 4-11 alongside manufacturing data and each contribution to sustainability calculated earlier.

Sustainability Performance Assessment				Sustainability weightage in Manufacturing			Manufacturing Data (Target)	Manufacturing sector (Target)	Sustainability data in manufacturing (actual)	**Factor** (actual/target)	**Indicator** contribution	Sustainability performance Score in Manufacturing	
		Sustainability elements	Sustainability Indicators	Pillars	Elements	Indicators	Manufacturing unit	Manufacturing unit	Manufacturing unit	Ratio	Indicator Contribution	Elements	Pillars
Elements representing the status of sustainability	Environment	Sustainability element 1	Indicator 1	27%	9%	3%	1	1	1	1.00	3%	9%	27%
			Indicator 2			3%	1	1	1	1.00	3%		
			Indicator 3			3%	1	1	1	1.00	3%		
		Sustainability element 2	Indicator 4		9%	5%	1	1	1	1.00	5%	9%	
			Indicator 5			5%	1	1	1	1.00	5%		
		Sustainability element 3	Indicator 6		9%	5%	1	1	1	1.00	5%	9%	
			Indicator 7			5%	1	1	1	1.00	5%		
	Social	Sustainability element 4	Indicator 8	18%	9%	5%	1	1	1	1.00	5%	9%	18%
			Indicator 9			5%	1	1	1	1.00	5%		
		Sustainability element 5	Indicator 10		9%	5%	1	1	1	1.00	5%	9%	
			Indicator 11			5%	1	1	1	1.00	5%		
	Economic	Sustainability element 6	Indicator 12	18%	9%	5%	1	1	1	1.00	5%	9%	18%
			Indicator 13			5%	1	1	1	1.00	5%		
		Sustainability element 7	Indicator 14		9%	5%	1	1	1	1.00	5%	9%	
			Indicator 15			5%	1	1	1	1.00	5%		
	Tech	Sustainability element 8	Indicator 16	18%	9%	9%	1	1	1	1.00	9%	9%	18%
		Sustainability element 9	Indicator 17		9%	9%	1	1	1	1.00	9%	9%	
	PM	Sustainability element 10	Indicator 18	18%	9%	9%	1	1	1	1.00	9%	9%	18%
		Sustainability element 11	Indicator 19		9%	9%	1	1	1	1.00	9%	9%	

Figure 4-11 Sustainability indicators' performance scores in manufacturing

Figure 4-11 shows the organisation's sustainability performance scores after assessing an operational efficiency-based indicator against the targets. The sustainability performance score is calculated using the following equations:

The indicator's performance = weight contribution x (actual sustainability data/company target SET). Equation 4-3

The indicator performance score is based on the sustainability indicator performance and the actual and target value ratio, accounting for the multiple stakeholders' preferences and influence in manufacturing. Figure 4-11 shows that not all SE in manufacturing has the same weight: each contributes to sustainability performance differently. This scoring system provides a better representation of sustainability performance in the organisation. It also considers the multiple stakeholders' roles, thus bridging the gap within current sustainability practices. The manufacturing organisation frequently re-visits their stakeholders' expectations to check for any material change in the manufacturing, new stakeholders, or revised sector targets.

This performance indication score will allow manufacturing organisations to directly understand the performance of sustainability indicators in manufacturing and the hotspots that require more attention than others. It will also provide grounds for the manufacturer to allocate resources appropriately.

4.1.4 Sustainability approach at step – IV

After completing step–III, the final step - IV is about communicating sustainability performance to multiple stakeholders. GRI 4.0 guidelines are becoming the default global communication standard since over 12,000 worldwide organisations are using them (GRI, 2018). However, other communication approaches exist besides publishing environmental, social, and economic advances via a corporate sustainability report using GRI 4.0 guidelines. After the sustainability team evaluates sustainability in manufacturing, it is up to the organisation which approach they should use in step - IV. However, GRI 4.0 guidelines are recommended due to their overwhelming use in manufacturing.

4.2 Evolution of the sustainability approach

The sustainability approach version-I was developed after the structured literature review and considering current sustainability assessment practices in the manufacturing sector. The approach's foundation was the researcher's MSc thesis in 'Advance Manufacturing', which focused on sustainability assessment approached in manufacturing and included an analysis of existing manufacturing sector approaches. It highlighted a gap between manufacturers' expectations and multiple stakeholders' prioritisations, as Jawahir (2010) identified.

The researcher has worked for 16 years in the manufacturing sector and has examined and reported sustainability data in the corporate environment. This experience includes managing and collating sustainability prioritisations of multiple stakeholders, including local councils, the manufacturing sector, suppliers, contractors, and consumers. This experience also helped me understand the manufacturer's challenges in meeting the multiple stakeholders' expectations alongside manufacturing operations and business. The researcher also examined some sophisticated assessment tools in manufacturing sectors not available in published literature through academic search engines.

Version–I was developed using the concept of measuring sustainability indicator values in manufacturing by ranking them in terms of their sustainability; this was achieved by considering multiple stakeholders' preferences. The sustainability approach version–I was built on the adopted concepts presented by Boulgar (2008), Permatasari (2006), and Nist (2015); the pairwise relationship and QFD approaches were incorporated to understand the prioritisations of multiple stakeholders in manufacturing. The elements adopted from Boulanger (2008) include splitting higher-level sustainability assessment approaches into sustainability pillars and elements and then into more measurable levels such as sustainability indicators in the manufacturing context.

The sustainability approach (version-I) was discussed with management in a manufacturing organisation approached for the study. This evaluation aimed to understand the manufacturer's reaction and feedback or criticism about the developed sustainability approach. The assessment approach was presented to the three functional managers, including an Engineering & Technical Manager responsible for the compliance issues, a Quality Manager, and a Supply Chain Manager. The participants were asked to provide feedback on the form (see appendix) to get their comments and understanding of the approaches, including utilisation and relevance in the manufacturing environment. The functional managers agreed to use the approach for validation within the organisation. Permission was granted to use sustainability data for academic purposes, not commercial or publishing purposes.

Version II was created after the appraisal of the sustainability approach (version–I) and accounting for suggestions and feedback (appraisal by industry experts and academic researchers). Different improvements were made based on the feedback during version- I's appraisal. Moreover, the new evaluated approach was named version - II. During the appraisal, it was suggested that the approach incorporates stakeholders' impact because different stakeholders have a different levels of influence in manufacturing. Therefore the stakeholders' prioritisation shall give consideration accordingly.

The sustainability approach was also presented during a POMS2017 conference at Macquarie Business School, Australia; the conference was on manufacturing and sustainability operations. An abstract of the conference presentation is in the appendix. This conference provided the opportunity to present and discuss the approach with experts.

The sustainability approach was then updated to version-III through a pilot study at the University of the Strathclyde and full validation in the manufacturing sector. The changes made and suggestions accepted are discussed in the following sections.

4.2.1 Appraisal of the sustainability assessment approach in manufacturing

After developing the sustainability approach, it was presented to and discussed with industry experts within a manufacturing organisation and researchers at the University of Strathclyde. This appraisal was carried out through three different sessions, and appraisals made are added in the appendix. The sustainability approach was reviewed and critically analysed during the appraisal using a similar pattern adopted by Hay's (2015) sustainability work and approach validation. The critical analysis steps were based on an approach developed by Young and Solomon (2009) (Hay, 2015; Young & Solomon, 2009).

These groups were asked to provide feedback using the appraisal form developed by the researcher. This feedback about the improvement was used to further develop the approach before presenting it for the pilot study and validation in the manufacturing organisation. The appraisal included questions covering how the approach would work, applicability in the manufacturing environment, flexibility, and features to understand multiple stakeholders. Table 4-2 gives a summary of the feedback. During the discussion and presentation, different suggestions and recommendations were made, some of which were accepted through team discussion and used to improve the approach further and increase manufacturers' likelihood of acceptance.

Table 4-2 Summary of the sustainability approach validation

Sustainability approach appraisal					
Groups	**Attributes & Experience**	**Applicability of approach**	**Understanding stakeholders expectations**	**Utility of the approach**	**Feedback & improvement about approach**
1. Industry experts providing consultancy to the manufacturing sector					
Industry expert -1	26 years	Excellent	Excellent	Good	Differenciate about internal and external stakeholders
Industry expert -2	20 years	Good	Excellent	Excellent	
2. Manufacturing company employees (Technical Manager, Quality Manager & Supply chain manager)					
Manager 1	22 years	Excellent	Excellent	Good	Training element should consider for the validation in manufacturing
Manager 2	12 years	Excellent	Excellent	Excellent	
Manager 3	20 years	Excellent	Good	Excellent	
3. Acadmic researchers at University of Strathclyde					
Researcher 1	2nd year in Phd	Excellent	Excellent	Good	Suggested full validation in manufacturing envirnment
Researcher 2	3rd years in Phd	Excellent	Excellent	Good	
Researcher 3	3rd years in Phd	Excellent	Good	Excellent	
Researcher 4	4th year in Phd	Excellent	Excellent	Excellent	
Researcher 5	4th year in Phd	Excellent	Excellent	Excellent	

The industry experts selected for the appraisal of the approach developed were consultants and had lead assessor role of sustainability in manufacturing and general. Manager –I,2 &3 were in the SMEs food and drinks company based in Scotland. The researchers were from the University of Strathclyde Glasgow, based in the sustainability field.
The sustainability approach's applicability: Most current sustainability practices and methods are too generic and fail to target manufacturing sustainability. The advantage of the 3SM approach lies in the fact that it was developed for and underwent validation in the manufacturing context; it is ideal for the industry.

Understanding the multiple stakeholders' expectations: incorporating a QFD-based approach into sustainability evaluation criteria is the unique feature of the tool. It is different from other approaches and provides a customised and tailored solution for manufacturers to compare general sustainability approaches. All panel experts appreciated this part of understanding the relevant stakeholders' expectations. After the initial discussion, stakeholder influence was incorporated into the approach. It was observed that different stakeholders have different degrees of influence on manufacturing —not just their expectations that need to be considered.

The sustainability approach's utility: the experts also wanted to understand and rate the sustainability approach based on how well it can be utilised in manufacturing and how useful it is to manufacturers.

After collating all the appraisals from different experts, changes were made to 'version-I' of the sustainability approach; it was updated to include stakeholders' influence and categorise stakeholders as either internal or external. Manufacturing functions were prioritised and added to the approach to understand those areas where sustainability issues were most pressing in the manufacturing process. This prioritisation will also help manufacturers allocate resources more effectively to improve the sustainability score.

Overall, sustainability experts rated each aspect of the sustainability approach as 'excellent' or 'good' and recommended its use in the manufacturing environment. Industry experts also recommended digitalising the 3SM sustainability approach to make it easier. One group also recommended applying for a grant to develop software for the 3SM QFD-based approach and patent it. These recommendations and feedback were added to version-I's sustainability approach, and the changes and additions formed version II.

4.2.2 Originality and impact of research

Sustainability assessment drives stakeholders' expectations and legislation to protect the environment and emphasise sustainable development for present and future generations. Various studies have indicated that it is essential to understand the internal and external stakeholders' expectations (Baron, 2014; Defra, 2007; L.-A. Ho, 2011). The QFD-based approaches have proven effective in understanding, managing, and prioritising stakeholders' demands (Huemann et al., 2016; Indrianti & Kumala, 2016; Springer et al., 2016b). Indicator-based approaches are highly effective in decision-making and understanding the situation, particularly in manufacturing (Oecd, 2007, 2008, 2009). This work's novelty is its QFD-based approach, which includes stakeholders' expectations in developing a customised approach for an organisation. The model enables companies to understand and collate relevant stakeholders' concerns and expectations. The QFD tool has not been explored before to assess sustainability performance in the manufacturing sector or evaluate an organisation's sustainability performance based on stakeholders' expectations and influence in manufacturing.

Traditional QFD-based approaches collate customers' and stakeholders' expectations, but the '3SM' model also addresses stakeholders' influence in prioritising sustainability's critical elements. Some stakeholders have high sustainability expectations but little impact on manufacturing and vice versa. A careful study of each segment of stakeholders' expectations and their relation to sustainability prioritisation using a QFD-based approach is the unique contribution of this work.

As previously stated, the '3SM' approach is a customised QFD-based approach that addresses and incorporates the expectations and influence of stakeholders in sustainability assessment after evaluating the fact that the current assessment practices are too general or are developed for one scenario. This proposed '3SM' model is an active approach highlighting those areas in organisations that regard sustainability more highly than the other functions and operations.

The second part of the thesis is validating the sustainability framework and '3SM model' in a manufacturing environment; this provides evidence of its effectiveness and relevance. This research contributes to bridging the manufacturer's and stakeholders' gap regarding manufacturing sustainability. An improved methodology is proposed to guide the industry in adopting a customised approach more relevant to manufacturing operations. From a practical viewpoint, this research provides a structured and systematic method for manufacturers to undertake an improved methodology to manage sustainability in their organisations.

4.3 Summary of the chapter

In this chapter, a sustainability assessment approach was developed. The chapter explained how it works, including the framework and how information flows from one step to another to generate relevant data for decision-makers. It also provides the basics and background of developing the sustainability approach, the process, and the appraisal criteria.

The approach was presented to and appraised by experts in the manufacturing sector and academic researchers. The appraisal confirmed that the approach bridges the gap between multiple stakeholders' preferences, as identified by the pairwise comparison and modified QFD approach. The approach highlighted the key manufacturing functions involved in the manufacturing sector. The sustainability approach was further recommended through a pilot validation and in manufacturing organisations using sustainability data.

Chapter 5 Sustainability approach validation in manufacturing

Chapter 5 is about the validation of the sustainability approach developed. It comprises the pilot study, pre-validation, and validation in the manufacturing environment using manufacturing sustainability data. The pre-validation of the approach was to ensure that it is suitable for an organisation. The matrices processing the stakeholders and manufacturing data provided meaningful information for the decision-makers. The pre-validation would also ensure the approach's suitability and relevance for the manufacturing sector.

During the pilot study (pre-validation), the researcher formed a sustainability team of four researchers from the University of Strathclyde. The sustainability team's task was to evaluate the sustainability approach by conducting a survey with multiple stakeholders and using their feedback in the approach matrices to assess whether the approach provides meaningful information for the decision-making process and areas for improvement. However, the multiple stakeholders at the pre-validation stage were not actual stakeholders of any manufacturing organisation. University students to consider external stakeholders for the pilot study. Four sustainability team members were the internal stakeholders for pre-validation purposes and sustainability preferences. Multiple stakeholders' preferences were collated through the sustainability approach matrices surveys to generate meaningful information for decision-makers. After the pilot study, the sustainability team appraised the outcome of the approach. The sustainability approach's appraisal considered its utility and effectiveness in garnering stakeholders' expectations and using them to prioritise SE, indicators, and manufacturing functions in the organisation.

After the appraisal and pre-validation, the approach was presented to and used in a manufacturing organisation (a manufacturing company from the drinks sector) for validation. The researcher and company management decided to form a team of employees for the validation process. Employee selection was based on their experience in manufacturing operations (to form a cross-functional sustainability team) and interest in the field. However, company management decided to validate the approach using manufacturing data but did not disclose details via written publications or other media, thus limiting its research and validation. Company management is permitted to use sustainability data of four different manufacturing sites of the organisation.

5.1 Pilot validation of the approach

The purpose of the pilot validation was to ensure that it was functioning well and fit for its purpose. The reason for conducting a pre-validation or pilot study was as follows

- Verifying how matrices and equations assess sustainability prioritisations and multiple stakeholders' influence.
- Develop a pairwise relation and use a QFD-based modified matrix to see if matrixes provide the correct information and mathematical equations.
- To check the GRI guidelines for SE and other representation with sustainability indicators, verify and discuss how the sustainability score provides sustainability performance information.

The sustainability assessment approach was pilot validated with a team of researchers at the University of Strathclyde, UK. The sustainability team, including the researcher, went through all steps, discussed the sustainability dimensions, modified survey forms, and prioritised SE in manufacturing. The team also verified the mathematical equations prioritising SE, manufacturing functions, normalisation and AHP tool, and scoring mechanisms.

The sustainability team used the sustainability approach version-II. The survey form in the appendix is used to gather internal and external stakeholders' prioritisation by collecting stakeholders' expectations and identifying their influence in a manufacturing context. The sustainability team considered other researchers at the University of the Strathclyde as external stakeholders for a virtual manufacturing organisation and asked them to prioritise sustainability pillars and sustainability prioritisation for a manufacturing organisation. Some of the completed surveys are available in the appendix. As the pre-validation key was to validate the matrices, their functionality and mathematical calculations were critiqued, emphasising how it processes the data. The external stakeholders in the pre-validation were six students in the university. Four internal stakeholders' preferences were gathered from the sustainability team itself. The second purpose was to understand and discuss the developed sustainability approach, providing meaningful information to the manufacturer and decision-makers about the organisation's actions and status of sustainability performance.

The sustainability data from multiple stakeholders was then used to prioritise SE and manufacturing functions. It also evaluated the sustainability indicators', and overall manufacturing scores based on the pattern explained in chapter 4.

Table 5-1 Sustainability approach appraisal by the sustainability team (Pilot or pre-validation)

<table>
<tr><th colspan="6">Sustainability approach appraisal - Pilot study</th></tr>
<tr><th>Groups</th><th>Attributes & Experience</th><th>Applicability of approach</th><th>Understanding stakeholders expectations</th><th>Utility of the approach</th><th>Feedback & improvement about approach</th></tr>
<tr><td colspan="6">Sustainability team set up at the University of Strathclyde for Pilot study</td></tr>
<tr><td>Researcher 1</td><td>3rd years in Phd</td><td>Excellent</td><td>Excellent</td><td>Good</td><td rowspan="4">1. Colour scheme for performing sustainability indicator
2. Sparate rating determination of each external stakeholder</td></tr>
<tr><td>Researcher 2</td><td>3rd years in Phd</td><td>Excellent</td><td>Good</td><td>Excellent</td></tr>
<tr><td>Researcher 3</td><td>3rd years in Phd</td><td>Excellent</td><td>Excellent</td><td>Excellent</td></tr>
<tr><td>Researcher 4</td><td>4th year in Phd</td><td>Excellent</td><td>Excellent</td><td>Good</td></tr>
</table>

Table 5-1 shows the abstract of the sustainability team’s appraisal of the pilot validation revealed an excellent method for categorising applicability in the manufacturing environment. Researchers 1,2,3 & 4 were from the University of Strathclyde Glasgow based. All four researchers worked on the sustainability theme and had command of the topic. Some team members suggested a colour scheme for the SE based on a performance score to help understand the performance category. The colour scheme shall use green for those meeting targets, red for elements failing, and orange for those behind the target and performing poorly. After the pilot validation and appraisal of the approach, it was decided that it has the full potential for sustainable performance in the manufacturing environment.

5.2 Approach validation in the manufacturing sector

Finally, the manufacturing environment tested the approach using sustainability and manufacturing data. The organisation selected for the validation was based in the UK, and the data were collected from four of the organisation's manufacturing sites in Scotland. The organisation requested that its details be kept confidential, although data can be used for research purposes, including validation of the approach. The organisation is classed as an SME and has up to 250 employees and revenue of £51Mio from the business based in Scotland.

The researcher led the manufacturing organisation's validation process for seven years, with different supply chain assignments. After presenting the management approach, the senior management consented to validate the approach and sustainability data approach. Management also allowed selecting a cross-functional team in the supply chain for approach validation. The sustainability team were selected based on their relevance to manufacturing, understanding, and availability during validation. The sustainability team needed to understand the sustainability approach and how it works. For this purpose, the researcher presented and discussed the team's sustainability approach, including its features and benefits, such as its flexibility. The four steps framework explained in Table 4-1 was followed for the validation. The sustainability team had five members, including the researcher. Considerable consideration was taken to ensure that the team knew sustainability and understood the supply chain's manufacturing functions. Team employees were from cross-functional departments such as engineering, production, maintenance, quality, and marketing. The researcher led the sustainability team to arrange the discussions and meetings, collate multiple stakeholders' expectations, and provide management updates.
The sustainability approach validation was of two levels, initially with the pilot study and then in the manufacturing organisation where a cross-functional team setup of five employees in the organisation over six weeks. The selection of the cross-functional team was based on employees' interest, knowledge and commitment during the validation phase.

The sustainability team collated data from internal and external stakeholders with a complete understanding of sustainability and sustainability tools. This included collating consumer data with the help of the sales and marketing team and collating sustainability data from internal and external stakeholders. The sustainability data of manufacturing was an aggregate of 5 different manufacturing sites. The data collected during this fed the sustainability tool and identified the hotspots in the supply chain. The results and information generated were then presented to senior management, who appreciated the systematic approach and validated usability, effectiveness and meaningful results—the validation form used for the validity of the approach is available in the appendix.

5.2.1 Approach validation of step – I

The route outlined in Figure 4-4 was adopted to validate step-I of the sustainability approach. The sustainability team and management agreed to use CSRs (2016-17 & 2018) to extract sustainability pillars, SE, and indicators used in the report. CSRs helped select system boundaries in supply chains and selected multiple stakeholders.

After discussion within the sustainability team, it was decided that a 'Gate to Gate' boundary would be used to collect sustainability data. The 'Gate to Gate' boundary selection has also supported the fact that multiple stakeholders are interested in the SE performance related to manufacturing, including emissions, packaging materials used on sites, and discharge consents from sites only.

At the end of step-I, the following outcomes were concluded:

- Sustainability team appointed (five employees including researcher);
- Manufacturing boundaries selection (Gate to Gate boundary selected);
- Multiple stakeholders in the organisation included seven external stakeholders and seven organisational managers.

This stakeholders list was essential to collate their sustainability preferences and the sustainability team to assess their business influence.

5.2.2 Approach validation of step – II

In Figure 4-5, Step II was followed to validate the approach developed. It started with selecting sustainability pillars and elements by the sustainability team with better manufacturing representation. After looking at the previous CSRs, the sustainability team selected Environmental, Social, and Performance management sustainability pillars for sustainability assessment. The sustainability team also chose SE from the GRI 4.0 aspect register because it had already decided on GRI 4.0 reporting standards for CSRs.

The sustainability team designed a questionnaire to ascertain stakeholders' expectations regarding the three sustainability pillars and SE represented in manufacturing. The questionnaire was flexible enough to allow for another sustainability element to be added later. The sustainability team identified multiple business stakeholders and sent them a questionnaire (in the appendix) to rate their SE expectations. It allowed stakeholders to provide their expectations and point out what manufacturers do not include in sustainability prioritisations. The sustainability team scored the influence of multiple manufacturing stakeholders, as in Figure 5-1.

Stakeholders impact analysis about Sustainability preferences in manufacturing				External Stakeholders expectations in manufacturing organisation														External stakeholders impact-(ESI)	Internal Stakeholders expectations in organisation							E(Xe)	Influence-e	Internal stakeholders impact-(ISI)
Primary	Sustainability Pillars		Tertiary level - Sustainability elements	Stakeholders 1 - Expectations	Stakeholders 1 - Influence	Stakeholders 2 - Expectations	Stakeholders 2 - Influence	Stakeholders 3 - Expectations	Stakeholders 3 - Influence	Stakeholders 4 - Expectations	Stakeholders 4 - Influence	Stakeholders 5 - Expectations	Stakeholders 5 - Influence	Stakeholders 6 - Expectations	Stakeholders 6 - Influence	Stakeholders 7 - Expectations	Stakeholders 7 - Influence		Engineering & Utilities	Primary & secondary production	Supply Chain & Distribution	Sales & Marketing	Projects & Procurement	Quality and Conformance Team	Operations & Logistics			
Sustainability score system in Manufacturing	SE	Environment	Emissions	5	4	4	4	4	2	5	4	4	5	4	5	4	4	17	4	4	4	5	5	4	4	4	4	17
			Energy consumption	5	4	4	4	4	2	5	4	4	5	4	5	4	4	17	4	4	4	4	5	4	3	4	4	16
			Water Utilisation	5	4	3	4	3	2	5	4	4	3	4	4	4	4	15	3	4	4	4	2	4	3	3	4	14
			Biodiversity	5	4	4	4	3	2	4	4	3	4	4	4	3	4	14	3	3	3	4	2	3	4	3	4	13
			Materials Consumption	5	4	5	4	3	2	5	4	4	4	4	4	5	4	17	4	5	4	4	5	3	5	4	4	17
		Social	Producer Responsibility (EPR)	4	4	4	4	3	2	5	4	3	4	4	4	5	4	15	5	3	3	4	4	4	4	4	4	15
			Employees Satisfaction	4	4	3	4	3	2	4	4	3	4	4	4	5	4	14	2	3	3	4	4	4	4	3	4	14
			Equal opportunities & Gender pay gap	4	4	4	4	3	2	3	4	3	4	4	4	5	4	14	4	3	3	3	3	4	5	4	4	14
			Health & safety	4	4	3	4	3	2	3	4	4	4	4	4	5	4	14	5	3	4	3	4	4	5	4	4	16
		PM	Program & policy	4	4	4	4	3	2	3	4	4	4	3	4	4	4	13	5	3	4	3	4	4	3	4	4	15
			Conformances	4	4	4	4	3	2	3	4	4	4	3	4	5	4	14	4	3	3	3	4	4	5	4	4	15

Figure 5-1 Stakeholders' expectations and influence matrix

Figure 5-1 shows stakeholders' expectations and influence over SE selected by the team. The team weighted all internal stakeholders with the same influence since they belong to the same segment group.

The sustainability team identified external stakeholders in the business realm, including the manufacturing sector, Environment Agency (EA), South Lanarkshire council, and supermarkets (three). The consumer purchases company-branded goods directly as they also produce goods for supermarkets under their labels. The team also asked the sales and marketing department to collate sustainability preferences (the marketing department already had data on customers' sustainability preferences). Each set of segments was managed separately since each had a different expectation level identified from the available data. In some cases, stakeholders were contacted by telephone to understand their preferences better. The sustainability team also gauged each stakeholder's influence via a rating of 1- 5, as listed in Figure 5-1. This took each stakeholder's role by weighting the expectations and influence of each sustainability element in manufacturing.

The sustainability team averaged the internal impact in the SE prioritisation. In the case of external stakeholders, different stakeholders have different expectations and are calculated differently — the internal and external stakeholders' impact is calculated in the matrix (Figure 5-1).

The ESI and ISI calculated in Figure 5-1 are used in Figure 5-2 to prioritise SE using a QFD-based matrix and pairwise comparison.

Relationships	RE
Strong	●
Moderate	○
Weak	▽

Column #					1	2	3	4	5	6	7	8	9	10	11
Relationship Matrix					Pairwise relationship /comparison among sustainability elements										
Strategic Requirements		Tertiary sustainability elements	ISI	ESI	Sustainability elements (SE i)										
					Environment 49%					Social 32%				PM 19%	
Primary level	Sustainability pillars	Tertiary level - Sustainability elements (SE j)	Internal Stakeholders Impact	External Stakeholders Impact	Emissions	Energy consumption	Water Utilisation	Biodiversity	Materials Consumption	Producer Responsibility (EPR)	Employees Satisfaction	Equal opportunities & Gender pay gap	Health & safety	Program & policy	Conformances
Sustainability score system in Manufacturing	Environment 49%	Emissions	17	17	●	○	▽	▽	●	▽			○	○	●
		Energy consumption	16	17	○	●	▽	▽	●	▽			○	○	○
		Water Utilisation	14	15	▽	▽	●	●	○	▽	▽		○	○	▽
		Biodiversity	13	14	▽	▽	●	●	●	○	▽	○	○	○	▽
		Materials Consumption	17	17	●	●	○	●	●	○	▽			○	▽
	Social 32%	Producer Responsibility (EPR)	15	15	▽	▽	▽	○	○	●	○	○		○	○
		Employees Satisfaction	14	14			▽	▽	▽	○	●	●	●	○	○
		Equal opportunities & Gender pay gap	14	14				○		○	●	●		○	
		Health & safety	16	14	○	○	○	○			●		●	○	○
	PM 19%	Program & policy	15	13	○	○	○	○	○	○	○	○	○	●	○
		Conformances	15	14	●	○	▽	▽	▽	○	○		○	○	●
Pairwise relationship		Pairwise elements relationship score (PR -E)			1234	1054	925	1275	1470	892	1126	760	1058	1160	1106
		Relative percentage score			10%	9%	8%	11%	12%	7%	9%	6%	9%	10%	9%
		Weight chart													

Figure 5-2 Sustainability elements prioritisation accounting for multiple stakeholders' roles

The sustainability team developed the relationships (strong, medium, weak, or no relationship) among SE using a pairwise relationship matrix shown in Figure 5-2. These relationships were developed by the sustainability team, who have an operational understanding of manufacturing functions. SE has interdependencies, reinforces each other in operations, and contributes to manufacturing sustainability. The PR-E score is calculated using the pairwise matrix and explained in chapter 4. It informs manufacturers and decision-makers in the organisation to allocate organisation resources to improve manufacturing's sustainability status. It also assesses which manufacturing function has a higher impact on sustainability, so the manufacturer pays attention and manages it accordingly.

Relationships	
Strong	●
Moderate	○
Weak	▽

Column #					1	2	4	5	7	8	9
Assessment using QFD-based tool				Pairwise relationship score (PR-E) in %	Manufacturing Functions in Supply chain — MF i						
Strategic Requirements					Engineering & Utilities	Primary & secondary production	Supply Chain & Distribution	Sales & Marketing	Projects & Procurement	Quality and Conformance Team	Operations & Logistics
Primary level	Sustainability	Pillars	Tertiary level - Sustainability elements (SE j)								
Sustainability score system in Manufacturing	SE j	Environment 49%	Emissions	10%	●	○	○		▽	▽	●
			Energy consumption	9%	●	●	○		▽		○
			Water Utilisation	8%	○	○		▽	▽		
			Biodiversity	11%	▽	▽	▽		▽	●	
			Materials Consumption	12%	●	●	▽		▽	○	○
		Social 32%	Producer Responsibility (EPR)	7%		○		●			
			Employees Satisfaction	9%		○				▽	
			Equal opportunities & Gender pay gap	6%				○	○	○	
			Health & safety	9%	○	▽	▽	▽			
		PM 19%	Program & policy	10%	▽	▽	○	○	▽	▽	○
			Conformances	9%	▽	▽			▽	▽	○
MF relative contribution			Manufacturing functions score (MF)		359	330	117	131	87	189	211
			Manufacturing functions rating in %		25%	23%	8%	9%	6%	13%	15%
			Weight chart - MF								

Figure 5-3 Sustainability elements performance in manufacturing functions

'MF' stands for manufacturing functions/departments weight (contribution) in conjunction with SE — it shows where the hotspots are in manufacturing. The highest percentage of the manufacturing functions shown in

Figure 5-3 accounts for 25% of the SE present in the engineering and utility department. This comprises most energy consumption, such as heating, boilers, and refrigeration, belonging to the engineering and utility section. It is essential to consider the engineering and utility department a top priority to improve sustainability performance and allocate resources.

At the end of step -II, the following outcome obtained shall be used as input to step III:

- Understand the multiple stakeholders' impact on manufacturing, SE score and manufacturing functions in the supply chain.
- SE pairwise relationships score and identification of the hotspots in manufacturing.

The pairwise relationships among SE and in contrast to manufacturing functions in Figure 5-2 and Figure 5-3 Sustainability elements performance in manufacturing functions provide the prioritisation of SE considering multiple stakeholders' impact and rank of manufacturing functions in the organisation contributing to sustainability manufacturing. As seen in Figure 5-2, SE's information from step II is further split into measurable sustainability and translated into sustainability in step III. Whereas the manufacturing functions information in Figure 5-3 provides the role of operations in the supply chain.

5.2.3 Approach validation of step – III

In step III, the SE selected and prioritised in step II are further split into measurable units called 'sustainability indicators'. An extensive list of sustainability indicators was gathered from published and grey literature and those used in the manufacturing sector (Appendix). Since the sustainability team has operational knowledge in manufacturing, selecting those sustainability indicators that best represent sustainability and manufacturing relevance is well placed. The sustainability team also used the Delphi technique, sector reports, and manufacturing operations to comprehend sustainability.

The sustainability team then prioritised sustainability indicators using AHP and normalisation techniques. Figure 5-4 lists the sustainability indicators selected through AHP and normalisation, which provided sustainability weight. It shows each sustainability indicator's relative weight and contribution to manufacturing, considering multiple stakeholders in context.

Indicators Role in performance

Relationships

1= the row is equally important as the column
3= slightly more important
5= more important
7= much more important
9= very much more important
0.33 = slightly less important
0.20 = less important
0.14 much less important

0.11 = very much less important

Sustainability score system in Manufacturing	Pillar	Indicators from Data Bank		Carbon emissions for unit of production	Electricity used for unit of production	Fossil fuels used for unit of producrion	Effluent water against unit production	BOD contents in water	Recycled materials used	Packaging waste to unit of production	Consumer wellbeing & responsibility	Employee satisfaction survey	Gender Pay gap	Equal opportunity policy and practices	Minor & major incidents on all sites	Safe working hours at work	Total initiatives and no. CI projects	Major & minor non-conformances in audits (Internal & external)
	Environment 49%	Emissions	Carbon emissions for unit of production	1.0	1.0	9.0	1.0	3.0	3.0	1.0	0.3	0.3	0.1	0.1	3.0	0.2	1.0	1.0
		Energy consumption	Electricity used for unit of production	1.0	1.0	3.0	0.3	0.2	7.0	5.0	0.2	0.2	0.3	0.3	1.0	0.3	0.3	1.0
			Fossil fuels used for unit of producrion	9.0	3.0	1.0	0.3	0.3	3.0	3.0	0.1	1.0	0.1	0.1	0.3	0.1	0.1	0.1
		Water Utilisation	Effluent water against unit production	1.0	0.3	0.3	1.0	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.3	0.3	0.3	0.3
		Biodiversity	BOD contents in water	3.0	0.2	0.3	0.3	1.0	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.3
		Materials Consumption	Recycled materials used	3.0	7.0	3.0	0.3	0.1	1.0	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.3
	Social 32%	Producer Responsibility (EPR)	Packaging waste to unit of production	1.0	5.0	3.0	0.3	0.1	5.0	1.0	0.3	0.3	0.1	0.1	1.0	0.1	0.1	0.1
			Consumer wellbeing & responsibility	0.3	0.2	0.1	0.3	0.1	1.0	0.3	1.0	3.0	0.3	0.3	1.0	0.3	0.3	0.3
		Employees Satisfaction	Employee satisfaction survey	0.3	0.2	1.0	0.3	0.1	0.3	0.3	3.0	1.0	5.0	3.0	1.0	1.0	0.3	1.0
		Equal opportunities & Gender pay gap	Gender Pay gap	0.1	0.3	0.1	0.1	0.1	0.3	0.1	0.3	5.0	1.0	3.0	3.0	3.0	3.0	3.0
			Equal opportunity policy and practices	0.1	0.3	0.1	0.1	0.1	0.3	0.1	0.3	3.0	1.0	1.0	0.3	1.0	0.3	0.3
		Health & safety	Minor & major incidents on all sites	3.0	1.0	0.3	1.0	0.3	0.1	1.0	1.0	1.0	1.0	0.3	1.0	1.0	0.1	1.0
			Safe working hours at work	0.2	0.3	0.1	0.3	0.1	0.1	0.1	0.3	1.0	0.2	1.0	1.0	1.0	0.2	1.0
	PM 19%	Program & policy	Total initiatives and no. CI projects	1.0	0.3	0.1	0.3	0.1	0.1	0.1	0.3	0.3	1.0	0.3	0.1	0.2	1.0	1.0
		Conformances	Major & minor non-conformances in audits (Internal & external)	1.0	1.0	0.1	0.3	0.3	0.1	0.1	0.3	1.0	3.0	0.3	1.0	1.0	1.0	1.0
	Total			25	21	22	7	6	22	13	8	18	14	10	15	10	8	12

Indicators from Data Bank	Normalised Assessment															Absolute Weigh	Pairwise relationship score (PR-E) in %	Relative function AHP Priority (%)
Carbon emissions for unit of production	0.0	0.0	0.4	0.2	0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.1	1.8	10%	10%
Electricity used for unit of production	0.0	0.0	0.1	0.1	0.0	0.3	0.4	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	1.3	9%	5%
Fossil fuels used for unit of producrion	0.4	0.1	0.0	0.1	0.1	0.1	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.2		4%
Effluent water against unit production	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	8%	8%
BOD contents in water	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	11%	11%
Recycled materials used	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	12%	12%
Packaging waste to unit of production	0.0	0.2	0.1	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.0	7%	7%
Consumer wellbeing & responsibility	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.7	9%	3%
Employee satisfaction survey	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.4	0.1	0.4	0.3	0.1	0.1	0.0	0.1	1.6		6%
Gender Pay gap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.3	0.2	0.3	0.4	0.3	1.9	6%	5%
Equal opportunity policy and practices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.1	0.0	0.0	0.7		2%
Minor & major incidents on all sites	0.1	0.0	0.0	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.1	1.0	9%	6%
Safe working hours at work	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.6		3%
Total initiatives and no. CI projects	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.5	10%	10%
Major & minor non-conformances in audits (Internal & external)	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.9	9%	9%
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	15.0	100%	100%

Figure 5-4 Indicators contribution to sustainability performance in the organisation

Sustainability Score System in Manufacturing (3SM)				Units of measurements	Elements weightage considering stakeholders impact	Actual (Sus. data) 2017-18	Sector Targets (2020)	Legal limits	Sustainability elements short term & long term targets: Short term 2018 (Targets)	Long term 2025 (Targets)	Individual elements contribution in overall sustainability	Sustainability elements performance considering stakeholders impact FY 2017-18 (%)	
Elements representing the status of sustainability	Environment 49%	Emissions	Carbon emissions for unit of production	(kg CO2e /l)	0.10	0.75	0.70	N/A	0.65	0.60	8.9%	86.7%	87%
		Energy consumption	Electricity used for unit of production	(Kwh /l)	0.05	0.27	0.25	N/A	0.25	0.20	4.3%	91.8%	
			Fossil fuels used for unit of producrion	(MJ/l)	0.04	20	20.0	N/A	18	16	3.7%		
		Water Utilisation	Effluent water against unit production	(l/l)	0.08	30	30.0	N/A	27	20	6.8%	88.7%	
		Biodiversity	BOD contents in water	(mg/L)	0.11	210	N/A	800	200	150	10.1%	95.2%	
		Materials Consumption	Recycled materials used	Recycled/non-recycled	0.12	0.30	0.40	N/A	0.40	0.60	9.1%	75.0%	
	Social 32%	Producer Responsibility (EPR)	Packaging waste to unit of production	(g/L)	0.07	110	90	N/A	100	80	6.7%	90.9%	80%
		Employees Satisfaction	Consumer wellbeing & responsibility	no.	0.03	4	N/A	N/A	5	7	2.3%	86.2%	
			Employee satisfaction survey	%	0.06	80%	N/A	N/A	90%	95%	5.8%		
		Equal opportunities & Gender pay gap	Gender Pay gap	%	0.05	25%	N/A	0%	20%	0%	3.7%	76.6%	
			Equal opportunity policy and practices	N/A	0.02	4	N/A	N/A	6	8	1.1%		
		Health & safety	Minor & major incidents on all sites	no.	0.06	26	N/A	N/A	12	2	2.6%	68.5%	
			Safe working hours at work	(hours)	0.03	1600	N/A	N/A	1500	1200	3.4%		
	PM 19%	Program & policy	Total initiatives and no. CI projects	no.	0.10	80	N/A	N/A	120	200	6.4%	66.7%	61%
		Conformances	Major & minor non-conformances in audits (Internal & external)	no.	0.09	22	N/A	N/A	12	6	5.0%	54.5%	

Figure 5-5 Sustainability indicators' performance in the organisation

The matrices are shown in Figure 5-4. Figure 5-5 shows the sustainability score system in manufacturing within a single organisation after assessing an operational efficiency-based indicator approach against the targets and sustainability data gathered from five manufacturing sites. The score and colour scheme in Figure 5-6 identifies the sustainability indicators, elements, and pillars in manufacturing against targets. The higher scores are marked green; amber and red colours require manufacturers and decision-makers to improve. The scores of sustainability indicators represented the multiple stakeholders' roles against industry targets. They are improving the indicators’ scores, directly and indirectly, addressing the multiple stakeholders' expectations in manufacturing.

The set targets for SE come from the manufacturing sector, organisation goals, and aspirations over and above the legal limits. Manufacturing's sustainability targets are derived from understanding the minimum permissible legal limits and sector targets.

The CSRs report 2017-18 and manufacturing sector reports determined the short- and long-term sustainability targets. During setting short- and long-term sustainability targets, the sustainability team communicated by telephone and email with companies in the Scottish manufacturing sector about sector initiatives, reports, and targets in reports. The manufacturing company had short-term sustainability targets for the next financial year, 2017-18, and long-term targets for 2025. At the end of step III, the following outcomes were obtained for use in reporting at step IV:

- Sustainability indicators contribution assessment (AHP & Normalisation) in context with multiple stakeholders' expectations and influence in manufacturing;
- Short- and long-term sustainability targets in the manufacturing organisation;
- Sustainability trends in manufacturing.

The sustainability indicators and overall sustainability scores in Figure 5-6 show the sustainability performance in manufacturing, which can be monitored weekly or monthly to follow progress and manufacturing trends. Although Figure 5-6 shows the accumulative number from all four manufacturing sites, individual sustainability scores can be generated for each site to allow for comparison between sites.

5.2.4 Approach validation of step – IV

Step-IV is about the communication approach of sustainability actions and how it is managed by the manufacturer to share with multiple stakeholders and general public members interested in the company's sustainability. The manufacturing company used GRI guidelines about sustainability reporting and decided to use the same.

5.3 Appraisal of approach in manufacturing

After validating the sustainability approach in a manufacturing organisation using actual data, the approach was appraised to understand the status of sustainability performance in a manufacturing organisation, management feedback, and effectiveness of the study and approach. Also, to conclude if and how the approach can help decision-makers and manufacturers to improve overall sustainability performance in manufacturing. Two senior managers responsible for sustainability performance and manufacturing operations discussed these matters. The results and scores in Figure 5-6, the overall sustainability performance process, and methodology were discussed with the sustainability team to validate the approach and improve sustainability performance and assessment aspects.

Table 5-2 Sustainability approach appraisal in the manufacturing sector

<table>
<tr><th colspan="6">Sustainability approach appraisal in the Manufacturing sector</th></tr>
<tr><th>Groups</th><th>Attributes & Experience</th><th>Applicability of approach</th><th>Understanding stakeholders expectations</th><th>Utility of the approach</th><th>Feedback & improvement about approach</th></tr>
<tr><td colspan="6">Sustainability team and functional managers in the manufacturing</td></tr>
<tr><td>Manager - I</td><td>25 Years</td><td>Excellent</td><td>Good</td><td>Good</td><td rowspan="7">1. Short term and long term sustainability targets in the manufacturing
2. Sustainability targets should also set with organisation and manufacturing sector targets</td></tr>
<tr><td>Manager - II</td><td>27 Years</td><td>Good</td><td>Excellent</td><td>Good</td></tr>
<tr><td>Team member I</td><td>20 Years</td><td>Excellent</td><td>Excellent</td><td>Good</td></tr>
<tr><td>Team member II</td><td>18 Years</td><td>Excellent</td><td>Excellent</td><td>Excellent</td></tr>
<tr><td>Team member III</td><td>15 Years</td><td>Good</td><td>Good</td><td>Excellent</td></tr>
<tr><td>Team member IV</td><td>12 Years</td><td>Excellent</td><td>Excellent</td><td>Excellent</td></tr>
<tr><td>Team member V</td><td>10 Years</td><td>Good</td><td>Excellent</td><td>Good</td></tr>
</table>

Table 5-2 shows the sustainability approach appraisal made in the manufacturing organisation by two senior managers and the sustainability team. The two managers were directly responsible for managing sustainability in the organisation. One was Engineering and Technical Manager, and the second was Supply chain Excellence Manager. The five team members were cross-functional departmental employees, including Engineering, Production, Procurement, Sales and Marketing. The sustainability approach understood that it accounted for stakeholders' requirements of the organisation. The appraisal of the approach shows the validity and utilisation aspects of manufacturing. Management was shown to consider using it for accounting for their actual stakeholders' preferences and concerns and feedback from internal stakeholders. The following aspects of the sustainability approach were appraised:

Applicability of the sustainability approach in manufacturing*:* it was suggested that most current sustainability practices and methods are too general, whereas the approach targeted vital sustainability issues in manufacturing. The majority of participants considered its applicability in manufacturing excellent.

Understanding multiple stakeholders' expectations in manufacturing: Using them to prioritise sustainability indicators and manufacturing hotspots relevant for decision-makers. Most team members and senior managers rated the approach as excellent in understanding the multiple stakeholders' expectations and incorporating those expectations in prioritising sustainability indicators and manufacturing operations.

The utility of the sustainability approach in manufacturing: this was about how flexible the approach is (as already mentioned, the company intend to use this approach in sustainability evaluation). Most participants, including senior managers in the organisation, classed it as excellent in the relevance category.

5.4 Chapter summary

In this chapter, the approach was prevalidated in the pilot study and validated in a manufacturing organisation using manufacturing and sustainability data from all their manufacturing sites. After the pilot study and manufacturing organisation, the approach critically appraised its legitimacy and consumption. The company management found that the approach relieved their concerns, considered stakeholders' aspirations, and highlighted involvement in manufacturing functions. It also shows the commitment to utilise the approach in the organisation.

Chapter 6 Discussion and conclusion

The thesis discussed the sustainability assessment approaches available in the literature and practice in the industrial sector (particularly in the manufacturing context) in contrast to identifying the gaps in the prioritising of the sustainability preferences in the manufacturing sector and identifying hotspots to appreciate for improving sustainability in manufacturing. Then proposed an alternative sustainability assessment approach in manufacturing, contributing to knowledge, bridging the shortcomings in approaches identified, and having practical implications in manufacturing. The approach developed for the manufacturing sector is flexible in accounting for a range of stakeholders' aspirations and understanding the varying demands of the business, including manufacturers. The approach developed is also a robust and precise assessment of sustainability performance to ensure it fits the purpose.

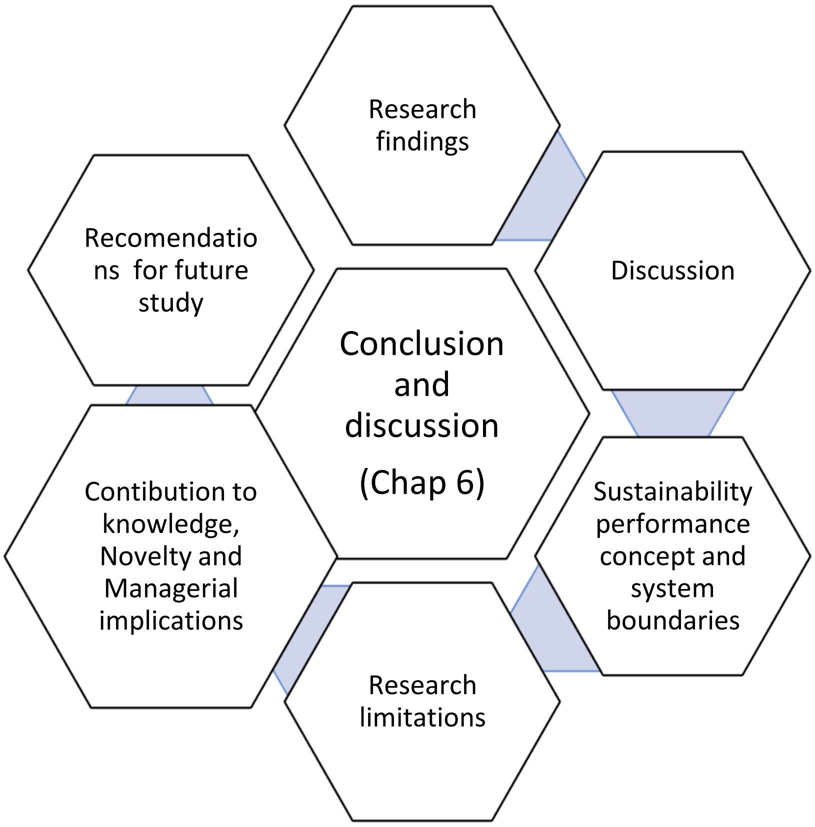

Figure 6-1 Overview of chapter 6

Figure 6-1 shows a discussion in the chapter that analysed the research problem using the approach's demonstration, appraisal completed by different groups, and proposed changes. The limitations of the research findings are highlighted, and potential improvements are discussed. This is followed by contributing to the approach's knowledge, findings, and novelty. Finally, it explains the future research areas and utilisation of the approach in other sectors. The research intends to address the issues raised in sustainability assessment and identified in the following research questions:

<u>RQ1: What are the current sustainability assessment approaches in the manufacturing sector, and what are their limitations?</u>

<u>RQ2: How can sustainability be assessed more robust, flexible, and precise in the manufacturing sector while incorporating multiple stakeholders' expectations?</u>

To address the research questions and aim, current sustainability assessment approaches were investigated by reviewing the available literature and considering current sustainability performance assessment practices in the manufacturing sector. In the literature review, sustainability approaches in the manufacturing context were discussed, along with their limitations. It also investigated the gaps in the current sustainability assessment approaches and methodologies available for manufacturing and multiple stakeholders' role in sustainability prioritisations. It assessed why and how the expectations and influence of relevant internal and external stakeholders could improve the status of sustainability in manufacturing. The proposed sustainability assessment approach uses a QFD-based methodology that accounts for multiple stakeholders' impact (expectations x influence) in prioritising sustainability indicators in manufacturing.

The review further discussed the QFD tool from a historical perspective and its usage in the sustainability domain. Also, how the QFD tool prioritises multiple stakeholder expectations can link the engineering characteristics (manufacturing functions) to identify sustainability. This also prioritises the manufacturing disciplines involve in manufacturing and their ranking in sustainability. This provides a ground for the manufacturer to allocate resources to improve sustainability in the supply chain. The scoring model also provides a quick assessment of the performance.

The sustainability approach developed for manufacturing involved consultation and appraisal with academic researchers, experts, and practitioners. The sustainability approach (3SM) addresses the existing gaps observed in the literature, and current sustainability assessment approaches. It incorporates and measures stakeholders' expectations and degree of influence in the manufacturing process. The approach (3SM) explains measuring indicators based on sustainability and multiple stakeholders' manufacturing roles. The approach's development and validation considered industry initiatives, local and international sustainability trends, legal limits, and acceptable and recommended sustainability indicators.

6.1 Research findings summary

The concepts of sustainability and sustainable manufacturing are becoming more widely known in the industry, with manufacturers developing better sustainability management approaches. However, there is no consensus about how the manufacturing sector should select sustainability indicators and performance criteria best suited to its operations' nature. Global warming, environmental changes, and biodiversity issues on the planet are, to some extent, directly related to manufacturing emissions and operations. Manufacturers intend to improve their practices and evaluate sustainability more precisely, using improved approaches suitable for their context and processes.

Consumers' and relevant stakeholders' expectations are absent in most current sustainability assessment approaches or overlooked in manufacturing sustainability assessments. The literature review found that most existing sustainability approaches cover various sectors but are not specific to manufacturing, and they underestimate the stakeholders' role in sustainability prioritisations. For this reason, a broad gap exists between the manufacturer and the multiple stakeholders' priorities and sustainability preferences. When applied in manufacturing, these approaches are also too generic; these approaches do not accommodate internal and external stakeholders' concerns or local and global sustainability trends. Although manufacturers seek to address the stakeholders' interests, including consumer satisfaction, current assessment approaches do not address or accurately prioritise sustainability issues. The research further highlights current assessment approaches and their limitations. It discusses the challenges in sustainability assessment, the gaps, and multiple stakeholders' roles in the assessment and the manufacturing context.

The literature review in chapter 2 and the sustainability approach presented in Chapter 4 identified the QFD tool structure, including its benefits in sustainability applications, especially with sustainable product development, and how it can be deployed to manage and prioritise stakeholders' expectations. Although the QFD tool is very good at managing stakeholders' preferences, the literature review observed that manufacturing sustainability has not yet been applied. Chapters 2 and 4 discussed the QFD-based approach and its development and debate among a select group of academic researchers and industry practitioners. It observed that the proposed sustainability approach accommodates stakeholders' influence in

manufacturing and took stock that different stakeholders have varying influences. It is essential to measure their influence when developing sustainability performance criteria; the approach dramatically helps.
The approach presented takes the QFD-based approach into account when evaluating sustainability assessment and performance. Another critical aspect is the extent of internal and external stakeholders' influence which typical QFD-based approaches do not consider. As noted earlier, some stakeholders have more considerable sway due to the company business they are involved in or the company's dependence. The proposed approach also prioritises the hotspots in manufacturing to account for the manufacturer when it is required to allocate organisation resources to improve manufacturing sustainability.

The approach was further subjected to pilot and full case validation in the manufacturing sector to assess its relevance. During this validation, criticism and suggestions were made to make the approach more relevant and robust for assessing sustainability. The validation of the approach in manufacturing provides the validity and contribution to knowledge itself.

6.2 Discussion

6.2.1 Sustainability performance concept and system boundaries

Academics and industry leaders are now more concerned about sustainability and sustainable manufacturing, but there is still no consensus about the fundamental issues in manufacturing sustainability assessment. In traditional sustainability approaches, three pillars are recognised: environmental, social, and economic, representing sustainability in general (H. Zhang & Haapala, 2015). Some approaches added new pillars, namely research, development, and performance management (NIST, 2015). The justification for these two additional pillars is that understanding sustainability will be limited without ongoing research and development, improvements in best practices, and better management of existing resources.

Another debated area is the definition of boundaries in manufacturing during a sustainability assessment of the supply chain. Not every sustainability approach identifies the sustainability boundaries in assessment since selecting sustainability boundaries can change the whole set of sustainability elements involved and the scope of the assessment. Therefore, it is highly recommended that the manufacturer decide and select a particular set of boundaries that are the most relevant and manageable in their manufacturing context. Gate-to-gate sustainability boundaries are considered the most appropriate in the manufacturing sector. They provide better control and make the relevant data available to manage and carry out sustainability assessments in manufacturing (O'Hare, 2010; Sala et al., 2015; Swartz, 2016). The manufacturer is responsible for managing the inputs and raw materials that enter the manufacturing organisations' gates and the finished goods and residual outputs that leave the premises gates. Multiple stakeholders are mainly interested in sustainability performance in the organisation, including how materials are consumed and resources used within the organisation domain.

After identifying the sustainability boundaries in assessment, the sustainability team's responsibility is collating and process the relevant data. Another task of the sustainability team is to select multiple pertinent manufacturing stakeholders with influence and expectations about sustainability, then evaluate their role in manufacturing and sustainability indicators prioritisation. The sustainability team should also prioritise manufacturing functions, as it is important for the manufacturer to understand the actions and decisions to improve sustainability in manufacturing.

The sustainability team should then translate multiple stakeholders' roles into organisation sustainability target setting and assess manufacturing data against it. Lastly, it should update sustainability numbers for multiple stakeholders and interested parties. GRI 4.0 guidelines are becoming the default standards for reporting sustainability worldwide (over 12,000 organisations use GRI guidelines and the sustainability aspects register). Unless the organisation has a different approach to updating sustainability results, they shall be standard. Reporting sustainability performance to multiple stakeholders is not part of the research.

6.2.2 The QFD tool and the sustainability approach

The literature review revealed no tools or practices that effectively select sustainability indicators relevant to the organisation and account for multiple stakeholders' expectations and influence in manufacturing. It is also observed that none of the current sustainability assessment approaches is designed for the gate-to-gate boundary approach (system boundaries) and considers manufacturing operations accountable for managing organisational resources.

The QFD tool, which has the advantage of managing multiple stakeholders' expectations, is used with some modification to derive meaningful information from manufacturing operations related to sustainability. The modified QFD-based tool, developed over the course of the current research, also indicates the hotspots in manufacturing — those areas where most sustainability elements are present. The proposed 3SM approach requires the sustainability team to select rather than pre-decided sustainability elements. Those elements often have no or less familiarity with the operations. It is also up to the manufacturer and sustainability team to understand and develop a relationship among sustainability elements and manufacturing functions using a QFD-based matrix to identify hotspots in manufacturing.

Further, AHP and normalisation tools prioritise sustainability indicators and establish the significance of each sustainability indicator. Sustainability indicators in manufacturing are divided by the target value multiplied by the weight assessed earlier; the calculations and equations have been discussed in chapter 4, and the weighting of each indicator in manufacturing. The goal is for the sustainability performance approach to develop a mechanism that accurately assesses sustainability performance to manage manufacturing operations' relevant processes.

6.3 Research limitations

This research acknowledges the importance and the demand for a customised sustainability assessment approach in manufacturing. It should be a robust methodology, one fit for the 21st century that enables the manufacturing sector to grasp and meet the various sustainability challenges of their geographic locations, the multiple stakeholders' satisfaction, meeting legal compliances, and industry targets in the years ahead.

However, there are limitations to this research, particularly concerning its scope, boundary setting, stakeholder selection, materials, and information about resource consumption. The validation of the approach was limited to one organisation and its four manufacturing sites' data. Thus, the findings cannot be generalised to the utilisation in other sectors; however, the approach's flexibility and consultation of relevant stakeholders, sustainability, and boundary selection provide an educated guess that it can still perform a meaningful sustainability assessment sectors.
The approach limitations are limited to the Gate to Gate approach discussed in the literature review. The manufacturer should consider a complete life cycle analysis; however, in the approach, legal accountability and reporting point of view, the manufacturer has to report the

materials utilized for the product and energy consumption in the business supply chain. Although each organisation has a chain link and depends on other stakeholders and organisations to provide raw materials, the subject approach concerns the manufacturing facility only. It also avoids the duplication of carbon footprints reporting to the government or manufacturing sector.

6.3.1 Sustainability approach validity

Due to the research's time constraints, the sustainability evaluation approach (3SM) primarily developed focused on manufacturing. The proposed sustainability evaluation approach (3SM) was developed and validated, and supported through the following stages:

- MSc project as a part of a research degree (EngD): the 3SM approach continues the master's thesis.
- Appraisals, Industry practitioners' appraisals: practitioners were industry consultants who specialise in developing various environmental and sustainability-related programs.
- Pilot study: setting up a sustainability team, gathering stakeholders' expectations and influence, and using the 3SM approach (Chapter 5).
- Manufacturing sector: finally, the 3SM approach was validated in a manufacturing organisation using sustainability data from five manufacturing sites.

Evaluation and validity of the sustainability approach (3SM) focused on three key aspects and the second research question of developing an improved sustainability approach:

- Validity: the degree to which the 3SM approach was validated in the manufacturing environment met multiple stakeholders' demands.
- Utility: the performance and utilisation of the 3SM approach in the manufacturing environment.

- Applicability: the extent to which the 3SM approach is considered limited to the manufacturing sector.

The sustainability approach's conceptual framework is discussed and validated in chapters 4 and 5.

6.4 Contribution to knowledge

The contribution to the knowledge resides in better understanding and presenting an alternative assessment approach of stakeholders' expectations and their influence in manufacturing, prioritising sustainability indicators, and investigating hotspots in manufacturing functions. Together, these have a more significant impact on sustainability. The sustainability assessment approach (3SM) in manufacturing, formalised through this research, provides an accurate means of measuring sustainability status and performance in manufacturing functions. The sustainability indicator scores estimate stakeholders' impact, manufacturing practices, future trends, and industry targets.

The review of sustainability assessment approaches in the literature, and practice shows a gap: assessing multiple stakeholders' expectations in sustainability prioritisation and actions. No customised sustainability assessment approach was available in the literature that considered the multiple stakeholder's expectations. Using it to prioritise sustainability elements and identify hotspots in manufacturing develop sustainability scores, representing multiple stakeholders' aspirations. Using a sustainability score system in manufacturing (3SM) has aspirations of multiple stakeholders and a novel approach. It demanded a flexible and customised approach that quickly selects relevant stakeholders, their expectations and influences in manufacturing, and forms that information into sustainability assessment criteria to measure sustainability performance. A more accurate sustainability assessment can use the 3SM approach; it reveals where the most effective manufacturing operations are situated within a particular organisation and how resources could best be utilised.

The indicator selection representing sustainability in manufacturing uses AHP and the normalisation approach to account for multiple stakeholders' roles and manufacturing operations. Further validation of the approach using a pilot study and manufacturing, the environment provides evidence for the research's effectiveness. The instructions for the 3SM approach to assessing sustainability in manufacturing are written in the thesis and contain novel elements contributing to the knowledge.

There is always room for improvement in any project or research, and certain areas in my sustainability approach can further improve, including validation of the approach assessment. I used the combined value of sustainability data of all four manufacturing sites. In contrast, I realised at the end and even with the discussion of internal management that each site should have its sustainability score and not the aggregate of all sites. This approach may help make a fair comparison among sites and identify the areas for improvement.

Secondly, evaluating the sustainability approach could collate more stakeholders' information in the assessment and more extensive data by including more consumer prioritisation of sustainability elements.

Another area is that sustainability tools should include a revision of sustainability targets and trends and require frequent adjustments to ensure they follow the market trends.

6.4.1 Novelty and originality of the work

This research addresses the following critical questions regarding sustainability assessment from a manufacturing perspective:

RQ1: What are the current sustainability assessment approaches in the manufacturing sector, and what are their limitations?

The systematic literature review concluded that current practices do not account for relevant stakeholders' expectations and influence. It is challenging to gauge current sustainability performance approaches' effectiveness without considering multiple stakeholders' roles.

RQ2: How can sustainability be assessed more robust, flexible, and precise in the manufacturing sector while incorporating multiple stakeholders' expectations?

This research has explored the challenge of designing and developing a methodology for assisting manufacturers in assessing sustainability. The improved methodology adopted is based on a modified QFD tool. The literature review revealed that it would be beneficial for managing sustainability, prioritisation, and stakeholders' role in the manufacturing sector. The modified version of the QFD-based matrix used stakeholders' expectations and degree of influence while prioritising sustainability elements in manufacturing. This is a relevant and value-added addition providing a more accurate assessment of sustainability prioritisation in manufacturing.

Motives for assessing sustainability come from multiple stakeholders' expectations, legislation to protect the environment, and manufacturing sector initiatives and targets. However, researchers pointed out that multiple stakeholders' expectations are not considered in sustainability assessment, and a broader gap exists between manufacturers and multiple stakeholders. This gap raises the question of the effectiveness of the various sustainability assessment approaches used today in the industry. It does not fit the design and satisfaction without incorporating the stakeholders' role in sustainability evaluation. Different studies have also shown a wide gap exists between stakeholders' and manufacturers' understanding of foundational sustainability issues. Via a comprehensive survey of organisations, it was demonstrated that for organisations to be innovative regarding sustainability, they must understand and involve internal and external stakeholders' expectations in measuring sustainability performance. QFD-based approaches have proven effective in understanding, managing, and prioritising stakeholders' demands for a new product or service that needs development. The indicator-based approach representing sustainability in manufacturing is considered highly effective in decision-making processes and understanding the situation, particularly in manufacturing.

The approach is novel because it accounts for the multiple stakeholders' expectations and influences prioritising sustainability in the organisation. This work's novelty is also of the approach developed and assessed—the QFD-based approach, which includes stakeholders' expectations in developing a customised strategy for an organisation. The model enables companies to understand and collate relevant stakeholders' concerns and expectations. The QFD tool has never been explored before, making it a unique way of evaluating an organisation's sustainability performance based on stakeholders' expectations and influence in manufacturing. A better understanding of stakeholders' expectations helps organisations design and prioritise sustainability and address their stakeholders' concerns. Some stakeholders have high sustainability expectations but little influence on manufacturing and vice versa and approach the stakeholder's expectations subject to their potential influence in the manufacturing and which represent in approach. A careful study of each segment of stakeholder's expectations and their relation to sustainability prioritisation using a QFD-based approach is the unique contribution of this work. This proposed sustainability approach is active and highlights those areas in organisations that regard sustainability more highly than the other functions and operations.

The second part of the thesis is developing and validating the sustainability approach model in a manufacturing environment; this provides effectiveness and relevance in the manufacturing sector. The research contribution resides in its bridging the gap between the manufacturer and stakeholders regarding sustainability in manufacturing. An improved methodology is proposed to guide the industry in adopting a customised approach more relevant to manufacturing operations. From a practical viewpoint, this research provides a structured and systematic approach for manufacturers to undertake an improved methodology to manage sustainability in their organisations.

6.4.2 Managerial implication of work

The proposed 3SM approach is novel, contributes knowledge, and has managerial implications in the manufacturing sector. The approach was developed with the researcher's interest and experience on the topic and then presented in the manufacturing sector. The sustainability data of four manufacturing business sites from different geographical locations were gathered and fed into the sustainability assessment approach. The sustainability approach and outcome were discussed with the manufacturer, industry experts, academic researchers, and practitioners' sustainability team. The different aspects of the approach, such as the relevance of the approach in manufacturing, suitability, and fit for the purpose, were gauged in the separate appraisal. The proposed 3SM approach was further improved with the feedback and affirmed the manufacturing environment's suitability.

The manufacturing organisation shows interest and plans to use the same approach for the following financial year. It addresses all their concerns, meets expectations, and accounts for multiple stakeholders in the business. Moreover, it highlighted the hotspots of manufacturing functions in the supply where further improvements can be made and benefit from allocated organisation resources that the organisation finds relevant and suitable to estimate and request the budget.

The sustainability assessment approach was developed, presented and validated using real data from manufacturing sites and organisation management decided to adopt the same methodology and approach in collating, managing and reporting sustainability. It shows the benefits and interest of the manufacturing sector in the proposed sustainability assessment. To make the approach more user-friendly and applicability the approach can be digitised which has been explained in the future study

6.5 Future Study

During the sustainability appraisal, some industry experts pointed out that if the proposed sustainability approach were digitised, it would have immense potential in the industry because it accounts for stakeholders' expectations and manufacturer interest and has the flexibility to take changing sustainability trends into account. A digitised version of the 3SM tool would be more user-friendly and helpful for small and medium-sized manufacturing companies without dedicated resources and resident experts. The digitised version can visually represent the findings and highlight urgent attention areas. It can also make it easy to do QFD-based analysis and process multiple stakeholders' information.

Experts also indicated that although the proposed sustainability approach was developed in the manufacturing discipline, the approach is flexible, takes relevant multiple stakeholders' roles into account, and was validated in a manufacturing organisation.
The proposed sustainability approach was validated in one manufacturing organisation using actual manufacturing data for one year. However, the study can extend to more years of data to see the past and future expected trends, as the sustainability approach validated in Food & Drinks organisation which has about 250 employees, four manufacturing sites, revenue up to £50 Mio based in Scotland. Moreover, the approach can be tested in large organisations with different demographics and sectors, such as the construction sector.

6.6 Summary of Chapter

The chapter raised the discussion and conclusion about the research, briefly outlined the research scope, an approach developed, how it addresses the research questions and bridges the gap by developing an alternative approach in the manufacturing sector. The chapter explained how a novel approach was used and further subjected to appraisal by experts and validated in the manufacturing sector. It discussed the managerial implications and identified further research aspects and extensions.

Work References

Abdel-Basset, M., Mohamed, R., Zaied, A. E.-N. H., & Smarandache, F. (2019). A hybrid pathogenic decision-making approach with quality function deployment for selection. *Symmetry*, *11*(903), 1–21.

Al-alwani, M. (2014). *Sustainability framework*. *February*.

Amini, M., & Bienstock, C. C. (2014). Corporate sustainability: An integrative definition and framework to evaluate corporate practice and guide academic research. *Journal of Cleaner Production*, *76*, 12–19. https://doi.org/10.1016/j.jclepro.2014.02.016

Amitrano, L. (2016). *What is sustainability? | BRANZ Build*. http://www.buildmagazine.org.nz/articles/show/what-is-sustainability/

Andrea Déri, Darren Swanson, P. B. (2007). Training manual. *Metal Finishing*, *105*(3), 74–75. https://doi.org/10.1016/S0026-0576(07)80624-6

Azapagic, A., & Perdan, S. (2000). Indicators of Sustainable Development : Guidelines and Methodologies. *Process Safety and Environmental Protection*, *78*(4), 243–261. https://doi.org/10.1205/095758200530763

Baines, T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J. R., Angus, J. P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., … Wilson, H. (2007). State-of-the-art in product-service systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *221*(10), 1543–1552. https://doi.org/10.1243/09544054JEM858

Ball, P. D., Evans, S., Levers, A., & Ellison, D. (2009). Zero carbon manufacturing facility — towards integrating material, energy, and waste process flows. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *223*(9), 1085–1096. https://doi.org/10.1243/09544054JEM1357

Bardi, U., Jakobi, R., & Hettiarachchi, H. (2016). Mineral Resource Depletion : A Coming Age of Stockpiling ? *BioPhysical Economics and Resource Quality*, *1*(1), 1–9. https://doi.org/10.1007/s41247-016-0004-x

Baron, R. (2014). The Evolution of Corporate Reporting for Integrated Performance. *Organisation for Economic Co-Operation and Development (OECD)*, *June* 1–35.

Baxter, T., Bebbington, J., Cutteridge, D., & Harvey, G. (2003). The Sustainability Assessment Model (SAM): Measuring Sustainable Development Performance. *Offshore Europe Conference - Proceedings*, *6563*(November 2015), 268–274. https://doi.org/10.1080/14486563.2006.9725127

Beerling, D. J., & Berner, R. A. (2005). Feedback and the coevolution of plants and atmospheric CO2.

Proceedings of the National Academy of Sciences of the United States of America, *102*(5), 1302–1305. https://doi.org/10.1073/pnas.0408724102

Belal, A. R., Cooper, S., Giordano-Spring, S., Maurice, J., & Cho, C. H. (2018). *Sustainability Accounting : Education, Regulation, Reporting and Stakeholders*. *21*(1), 1–200.

Benini, L., Mancini, L., Sala, S., Schau, E., Manfredi, S., & Pant, R. (2014). *Normalisation method and data for Environmental Footprints*. https://doi.org/10.2788/16415

Benner, M., Linnemann, A. R., Jongen, W. M. F., & Folstar, P. (2003). Quality Function Deployment (QFD) - Can it be used to develop food products? *Food Quality and Preference*, *14*(4), 327–339. https://doi.org/10.1016/S0950-3293(02)00129-5

Bernard, S. (2011). Remanufacturing. *Journal of Environmental Economics and Management*, *62*(3), 337–351. https://doi.org/10.1016/j.jeem.2011.05.005

Bevilacqua, M., Ciarapica, F. E., & Marchetti, B. (2012). Develop and test a new fuzzy-QFD approach for characterizing customers' extra virgin olive oil rating. *Food Quality and Preference*, *24*(1), 75–84. https://doi.org/10.1016/j.foodqual.2011.09.005

Blaikie, N. W. H. (2000). *Designing social research : the logic of anticipation*. Polity Press.

Boiral, O., & Heras-Saizarbitoria, I. (2020). Sustainability reporting assurance: Creating stakeholder accountability through hyperreality? *Journal of Cleaner Production*, *243*, 1–17. https://doi.org/10.1016/j.jclepro.2019.118596

Boulanger, P.-M. (2008). Sustainable development indicators: a scientific challenge, a democratic issue. *Sapiens*, *1*, 44–59. https://doi.org/10.5194/sapiens-1-59-2008

Bourne, L. (2011). Advising upwards: managing the perceptions and expectations of senior management stakeholders. *Management Decision*, *49*(6), 1001–1023. https://doi.org/10.1108/00251741111143658

Bourne, L., & Walker, D. H. T. (2008). Project relationship management and the Stakeholder Circle™. *International Journal of Managing Projects in Business*, *1*(1), 125–130. https://doi.org/10.1108/17538370810846450

BP. (2013). *Leave it in the ground! How fossil fuel extraction affects biodiversity*. https://theconversation.com/leave-it-in-the-ground-how-fossil-fuel-extraction-affects-biodiversity-19484

Bragança, L., Mateus, R., Koukkari, H., Bragança, L., Mateus, R., & Koukkari, H. (2010). Building Sustainability Assessment. *Sustainability*, *2*(7), 2010–2023. https://doi.org/10.3390/su2072010

Brissaud, D., & Zwolinski, P. (2017). The Scientific Challenges for a Sustainable Consumption and Production Scenario: The Circular Reuse of Materials for the Upgrading and Repurposing of

Components. *Procedia CIRP*, *61*, 663–666. https://doi.org/10.1016/j.procir.2016.11.148

Brundtland, G. H. (1987). Our Common Future: Report of the World Commission on Environment and Development. *Medicine, Conflict and Survival*, *4*(1), 300. https://doi.org/10.1080/07488008808408783

Brunner, P. H., & Rechberger, H. (2004). Practical handbook of material flow analysis. *The International Journal of Life Cycle Assessment*, *9*(5), 337–338. https://doi.org/10.1007/BF02979426

BSI. (2012). PUBLICLY AVAILABLE SPECIFICATION Specification of common management system requirements as a framework for integration. *BSI*, *2*, 45.

BSR. (2008). *Stakeholder Engagement*. 12–14. https://doi.org/10.1201/b18120

Camarinha-matos, L. M., & Falcão, A. J. (2016). *Innovation for Cyber-Physical Systems*.

Camarinha-Matos, L. M., Falcão, A. J., Vafaei, N., & Najdi, S. (2016). Technological innovation for cyber-physical systems: 7th IFIP WG 5.5/SOCOLNET advanced doctoral conference on computing, electrical and industrial systems, DoCEIS 2016 Costa de Caparica, Portugal, April 11–13, 2016 proceedings. *IFIP Advances in Information and Communication Technology*, *470*(October 2017). https://doi.org/10.1007/978-3-319-31165-4

Carnevalli, J. A., & Miguel, P. C. (2008). Review, analysis and classification of the literature on QFD-Types of research, difficulties and benefits. *International Journal of Production Economics*, *114*(2), 737–754. https://doi.org/10.1016/j.ijpe.2008.03.006

Cleveland, C. J., & Ruth, M. (1998). Indicators of Dematerialization and the Materials Intensity of Use. *Journal of Industrial Ecology*, *2*(3), 15–50. https://doi.org/10.1162/jiec.1998.2.3.15

Coke. (2014). *Coca-Cola 2013/2014 Sustainability Report*. 55–62.

Coke. (2017). *Our Mission , Vision & Values*.

Coulson, J. (2014). *Sustainable Use of Wood in Construction - Coulson - Wiley Online Library*. http://onlinelibrary.wiley.com/book/10.1002/9781118539613;jsessionid=CD2A18D84B98FBF8C7C880710F88FE8E.f01t02

Cradle, C. to. (2014). *Version 3.1 cradle to cradle certified product standard*.

Creswell, J. W. (2014). *Research design : qualitative, quantitative, and mixed method approaches*.

Davig, B. T., Nie, J., & Smith, A. L. (2014). *Evaluating a Year of Oil Price Volatility*. 3–28.

Day, T., & Tosey, P. (2011). Beyond SMART? A new framework for goal setting. *Curriculum Journal*, *22*(4), 515–534. https://doi.org/10.1080/09585176.2011.627213

Defra. (2006). Environmental Key Performance Indicators Environmental Key Performance Indicators.

Environmental Pollution, *102*(1), 711–715. https://doi.org/10.1111/j.1747-6593.2001.tb00302.x

Defra. (2007). The Food Industry Sustainability Strategy. *Nutrition & Food Science*, *37*(5), 124. https://doi.org/10.1108/nfs.2007.01737eab.036

DEFRA. (2006). Environmental Key Performance Indicators: Reporting Guidelines for UK Buisness. *Department for Environment Food and Rural Affairs*, 74.

Delai, I., & Takahashi, S. (2011). Sustainability measurement system: a reference model proposal. *Social Responsibility Journal*, *7*(3), 438–471. https://doi.org/10.1108/17471111111154563

Delloitte 2020. (n.d.). *2021 banking industry outlook | Deloitte Insights*. Retrieved January 31, 2021, from https://www2.deloitte.com/us/en/insights/industry/financial-services/financial-services-industry-outlooks/banking-industry-outlook.html

Deloitte. (2012). *Sustainability for consumer business companies: A story of growth Contents*. 14.

Despeisse, M. (2015). Sustainable Manufacturing Processes. *Statewide Agricultural Land Use Baseline 2015*, *1*(April), 2010–2013. https://doi.org/10.1017/CBO9781107415324.004

Devuyst, D. (2001). *Introduction to sustainability assessment at the local level*. https://books.google.co.uk/books?hl=en&lr=&id=xacqlipuiX4C&oi=fnd&pg=PA1&dq=devuyst+2001+sustainability&ots=_PlfUr6FGM&sig=BrTXvJiqhg8xUUhBbJ9pOjvVlaY

Distell. (2014). *Distell*.

Distell. (2017). *Report 2017*.

E.G., H. (2005). Consumption and the Rebound Effect - An Industrial Ecology Perspective. *Journal of Industrial Ecology*, *9*(1), 85 – 98.

Easterby-Smith, Richard Thorpe, P. J. (2012). *Management Research*. *4*. https://books.google.co.uk/books?id=ahbhMb-R7MQC&printsec=frontcover&dq=Easterby-Smith+et+al.,+2012&hl=en&sa=X&ved=0ahUKEwjQqPSU0qfNAhXEJMAKHfD8CC4Q6AEIHjAA#v=onepage&q=Easterby-Smith et al.%2C 2012&f=false

Egilmez, G., Kucukvar, M., & Tatari, O. (2013). Sustainability assessment of U.S. manufacturing sectors: An economic input output-based frontier approach. *Journal of Cleaner Production*, *53*, 91–102. https://doi.org/10.1016/j.jclepro.2013.03.037

Ehrenfeld, J. R. (2005). *The Roots of Sustainability The Roots of Sustainability*. *46*(2).

Elkington, J. (1997). Cannibals with forks. *Cannibals with Forks: The Triple Bottom Line of 21st CenturyThe Triple Bottom Line of 21st Century*, *April*, 1–16. https://doi.org/http://doi.wiley.com/10.1002/tqem.3310080106

EPA. (2014). *Global Greenhouse Gas Emissions Data | Greenhouse Gas (GHG) Emissions | US EPA*.

https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

Essos. (2014). *ENERGY The Energy Savings Opportunity Scheme Regulations 2014*. *1643*. http://www.legislation.gov.uk/

Etsy, D. C., & Andonov, B. (2005). *2005 Environmental Sustainability Index*.

Evans, K. M., Information Plus (Firm : Wylie, T. ., & Gale Group. (2005). *The environment : a revolution in attitudes*. Thomson Gale.

Exposing Game. (2015). *Human Population Growth: "Anomalous and Unnatural" | Exposing the Big Game*. https://exposingthebiggame.wordpress.com/2015/06/26/human-population-growth-anomalous-and-unnatural/

Fallis, A. . (2013). forging and forming sustainability in Australia. *Journal of Chemical Information and Modeling*, *53*(9), 1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Fan, C., Carrell, J. D., & Zhang, H. C. (2010). An investigation of indicators for measuring sustainable manufacturing. *Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology, ISSST 2010*. https://doi.org/10.1109/ISSST.2010.5507764

Faulkner, W., & Badurdeen, F. (2014). Sustainable Value Stream Mapping (Sus-VSM): Methodology to visualize and assess manufacturing sustainability performance. *Journal of Cleaner Production*, *85*, 8–18. https://doi.org/10.1016/j.jclepro.2014.05.042

Filimonau, V. (2016). *Life Cycle Assessment (LCA) and Life Cycle Analysis in Tourism*. https://doi.org/10.1007/978-3-319-26224-6

Finnveden, G., & Moberg, Å. (2005). Environmental systems analysis tools – an overview. *Journal of Cleaner Production*, *13*(12), 1165–1173. https://doi.org/10.1016/J.JCLEPRO.2004.06.004

Floyd, D. W., Vonhof, S. L., & Seyfang, H. E. (1995). *Forest Sustainability: A Discussion Guide for Professional Resource Managers* (p. P.322). Society of American Foresters. http://www.ingentaconnect.com/contentone/saf/jof/2001/00000099/00000002/art00004?crawler=true

Fobbe, L., & Hilletofth, P. (2021). The role of stakeholder interaction in sustainable business models. A systematic literature review. *Journal of Cleaner Production*, *327*(March), 129510. https://doi.org/10.1016/j.jclepro.2021.129510

Fortuin, K. P. J., van Koppen, C. S. A., & Kroeze, C. (2013). The contribution of systems analysis to training students in cognitive interdisciplinary skills in environmental science education. *Journal of Environmental Studies and Sciences*, *3*(2), 139–152. https://doi.org/10.1007/s13412-013-0106-3

Fuss, S., Canadell, J. G., Peters, G. P., Tavoni, M., Andrew, R. M., Ciais, P., Jackson, R. B., Jones, C. D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M. R., Sharifi, A., Smith, P., & Yamagata,

Y. (2014). Betting on negative emissions. *Nature Climate Change*, *4*(10), 850–853. https://doi.org/10.1038/nclimate2392

Galli, A., Kitzes, J., Niccolucci, V., Wackernagel, M., Wada, Y., & Marchettini, N. (2012). Assessing the global environmental consequences of economic growth through the Ecological Footprint: A focus on China and India. *Ecological Indicators*, *17*, 99–107. https://doi.org/10.1016/j.ecolind.2011.04.022

Garmendia, E., Prellezo, R., Murillas, A., Escapa, M., & Gallastegui, M. (2010). Weak and strong sustainability assessment in fisheries. *Ecological Economics*, *70*(1), 96–106. https://doi.org/10.1016/j.ecolecon.2010.08.001

Goodland, R., & Bank, T. W. (1995). *THE CONCEPT OF*. 1–24.

GRI. (2014). G4 Sustainability Reporting Guidelines. *Global Reporting Initiative*, 1–97. https://www.globalreporting.org/standards/g4/Pages/default.aspx

GRI. (2018). *SDD - GRI Database*. http://database.globalreporting.org/

Guba, E. G., & Lincoln, Y. S. (1994). Competing Paradigms in Qualitative Research. *Handbook of Qualitative Research*, 105–117. https://doi.org/http://www.uncg.edu/hdf/facultystaff/Tudge/Guba%20&%20Lincoln%201994.pdf

Günther Bachmann, I. N. (2005). Increasing the Role of Stakeholders in Sustainability Strategies. *Sustaining Sustainability*, *January*, 1–6.

Hák, T., Moldan, B., Dahl, A. L., & International Council for Science. Scientific Committee on Problems of the Environment. (2007). *Sustainability indicators : a scientific assessment*. Island Press. https://www.worldcat.org/title/sustainability-indicators-a-scientific-assessment/oclc/74569191

Hallstedt, S. I., Bertoni, M., & Isaksson, O. (2015). Assessing Sustainability and Value of Manufacturing Processes: A case in the aerospace industry. *Journal of Cleaner Production*, *108*, 169–182. https://doi.org/10.1016/j.jclepro.2015.06.017

Harris, J. M. (2003). *Sustainability and Sustainable Development*. *February*, 1–12.

Hartwick, J. M. (1991). The non-renewable resource exploring-extracting firm and the r% rule. *Resources and Energy*, *13*(2), 129–143. https://doi.org/10.1016/0165-0572(91)90011-Q

Hauschild, M., Jeswiet, J., & Alting, L. (2005). From Life Cycle Assessment to Sustainable Production: Status and Perspectives. *CIRP Annals - Manufacturing Technology*, *54*(2), 1–21. https://doi.org/10.1016/S0007-8506(07)60017-1

Hay, L. (2015). *Generic models of technical systems sustainability*. *June*.

Hejres, S., Braganza, A., & Aldabi, T. (2017). Investigating the Effectiveness of Leadership Styles on

Instructional Leadership and Teachers Job Expectancy in Kingdom of Bahrain. *American Journal of Educational Research*, *5*(7), 694–709. https://doi.org/10.12691/education-5-7-2

Ho, L.-A. (2011). Industrial Management & Data Systems Article information : *Industrial Management & Data Systems*, *111*(1), 113–131. https://doi.org/10.1108/SCM-03-2014-0108

Ho, W., Dey, P. K., & Lockström, M. (2011). Strategic sourcing: A combined QFD and AHP approach in manufacturing. *Supply Chain Management*, *16*(6), 446–461. https://doi.org/10.1108/13598541111171093

Horan, L. F. (2022). The dynamic changes of customer requirements for sustainable design over time in quality function deployment. *Production and Manufacturing Research*, *10*(1), 42–61. https://doi.org/10.1080/21693277.2022.2039316

Huemann, M., Eskerod, P., & Ringhofer, C. (2016). *Rethink! Project Stakeholder Management*. *V*(V), xvii, 213 pages.

Huse, M., & Rindova, V. P. (2001). Stakeholders' Expectations of Board Roles: The Case of Subsidiary Boards. *Journal of Management and Governance*, *5*(2), 153–178. https://doi.org/10.1023/A:1013017909067

Indrianti, N., & Kumala, D. (2016). Qfd Approach for Quality Improvement of a Sustainable Product-Service System. *Interernational Journal of Service Management and Sustainability*, *1*(1).

Ingarao, G., Di Lorenzo, R., & Micari, F. (2011). Sustainability issues in sheet metal forming processes: An overview. *Journal of Cleaner Production*, *19*(4), 337–347. https://doi.org/10.1016/j.jclepro.2010.10.005

Institute, Q. (2017). *Symposium on QFD Abstracts* (Vol. 0847).

ISO-14031. (2013). *ISO 14031:2013 - Environmental management -- Environmental performance evaluation -- Guidelines*. http://www.iso.org/iso/catalogue_detail.htm?csnumber=52297

Jayal, A. D., Badurdeen, F., Dillon, O. W., & Jawahir, I. S. (2010). Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. *CIRP Journal of Manufacturing Science and Technology*, *2*(3), 144–152. https://doi.org/10.1016/j.cirpj.2010.03.006

Jon A Krosmick, L. R. F. (1997). *rating scale.pdf*.

Jones, D. (2016). *S&P Dow Jones Indices» Dow Jones Sustainability Indices» Overview*. http://www.djindexes.com/sustainability/

Jørgensen, A. (2013). Social LCA - A way ahead? *International Journal of Life Cycle Assessment*, *18*(2), 296–299. https://doi.org/10.1007/s11367-012-0517-5

Joseph A., M. J. (1991). *STES DE NECKER'S GENERAL WEBSITE AND BLOG FOR GENERAL MATTERS: Hoe lank kan die aarde nog die mens se aanslag afweer?* http://stesdeneckers.blogspot.co.uk/2012/10/hoe-lank-nog-kan-die-aarde-die-mensse.html

Joung, C. B., Carrell, J., Sarkar, P., & Feng, S. C. (2013a). Categorization of indicators for sustainable manufacturing. *Ecological Indicators*, *24*, 148–157. https://doi.org/10.1016/j.ecolind.2012.05.030

Joung, C. B., Carrell, J., Sarkar, P., & Feng, S. C. (2013b). Categorization of indicators for sustainable manufacturing. *Ecological Indicators*, *24*, 148–157. https://doi.org/10.1016/j.ecolind.2012.05.030

Jovane, F., Westkämper, E., & Williams, D. J. (David J. . (2009). *The manuFuture road : towards competitive and sustainable high-adding-value manufacturing*. Springer. https://books.google.co.uk/books?hl=en&lr=&id=uGpxGKNS1IIC&oi=fnd&pg=PR17&dq=Jovane,+F.,+Westkämper,+E.+and+Williams,+D.+(2009),+The+Manufuture+Road,+Springer,+Berlin.&ots=0Npxdsk7nh&sig=SPEXtJhKnYZYtdd3DH_zrMQp0Ic#v=onepage&q&f=false

Jr., A. S. T., & Gati, A. M. (2009). Environmental Value Stream Mapping (EVSM) as sustainability management tool. *PICMET '09 - 2009 Portland International Conference on Management of Engineering & Technology*, 1689–1698. https://doi.org/10.1109/PICMET.2009.5261967

Kajikawa, Y. (2008). Research core and framework of sustainability science. *Sustainability Science*, *3*(2), 215–239. https://doi.org/10.1007/s11625-008-0053-1

Kidd, C. V. (1992). The evolution of sustainability. *Journal of Agricultural and Environmental Ethics*, *5*(1), 1–26. https://doi.org/10.1007/BF01965413

Kloepffer, W. (2008). Life Cycle Sustainability Assessment of Products (with Comments by Helias A. Udo de Haes, p. 95). *International Journal Life Cycle Assessment*, *13*(2), 89–95. https://doi.org/http://dx.doi.org/10.1065/lca2008.02.376

Kolk, A. (2000). *Economics of Environmental Management*. https://dare.uva.nl/search?identifier=ef0ef2e3-2d3a-4e73-8b62-c0b73080ee99

Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renewable and Sustainable Energy Reviews*, *69*(October 2016), 596–609. https://doi.org/10.1016/j.rser.2016.11.191

Kumar, R. (2011). *Research Methodology*.

Kutz, M., & Elkamel, A. (2010). *Environmentally conscious fossil energy production*. Wiley.

Law, E., Earth, I., & Information, S. (2010). *Environmental Performance*.

Learning and Teaching Centre. (2010). Developing Checklists. *BCIT*.

Lee, M. T., & Raschke, R. L. (2020). Innovative sustainability and stakeholders' shared understanding: The secret sauce to "performance with a purpose." *Journal of Business Research*, *108*(June 2019), 20–28. https://doi.org/10.1016/j.jbusres.2019.10.020

Lozano, R., Carpenter, A., & Huisingh, D. (2015). A review of "theories of the firm" and their contributions to Corporate Sustainability. *Journal of Cleaner Production*, *106*, 430–442. https://doi.org/10.1016/j.jclepro.2014.05.007

Malamud, A. (2015). Social Revolution or Political Takeover? *Latin American Perspectives*, *42*(1), 11–26. https://doi.org/10.1177/0094582X13492710

Manetti, G., & Toccafondi, S. (2012). The Role of Stakeholders in Sustainability Reporting Assurance. *Journal of Business Ethics*, *107*(3), 363–377. https://doi.org/10.1007/s10551-011-1044-1

Mangili, P. V., Santos, L. S., & Prata, D. M. (2019). A systematic methodology for comparing the sustainability of process systems based on weighted performance indicators. *Computers and Chemical Engineering*, *130*. https://doi.org/10.1016/j.compchemeng.2019.106558

Mani, M., Madan, J., Lee, J. H., Lyons, K. W., & Gupta, S. K. (2013). Review on Sustainability Characterization for Manufacturing Processes Review on Sustainability Characterization for Manufacturing Processes. *Nistir 7913*. https://doi.org/10.6028/NIST.IR.7913

Mann, M. E. (2014). *Earth Will Cross the Climate Danger Threshold by 2036*. http://www.scientificamerican.com/article/earth-will-cross-the-climate-danger-threshold-by-2036/

Mascarenhas, A., Coelho, P., Subtil, E., & Ramos, T. B. (2010). The role of common local indicators in regional sustainability assessment. *Ecological Indicators*, *10*(3), 646–656. https://doi.org/10.1016/j.ecolind.2009.11.003

Megayanti, W., Anityasari, M., & Ciptomulyono, U. (2018). Sustainable suppy chain value stream mapping (Ssc-Vsm) the application in two bottle drinking water companies. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, *2018-March*, 3573–3585. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051495688&partnerID=40&md5=1d5b6e4d5cee1b9bb9f90751b696453c

Melkonyan, A., Gottschalk, D., & Vasanth, V. K. (2017). Sustainability assessments and their implementation possibilities within the business models of companies. *Sustainable Production and Consumption*, *12*(January), 1–15. https://doi.org/10.1016/j.spc.2017.04.001

Mikes Hawes. (2015). *SMMT*.

Mu, E., & Pereyra-Rojas, M. (2017). *Practical Decision Making*. *2012*. https://doi.org/10.1007/978-3-319-33861-3

Mulcahy, R. (2012). *PMP exam prep : accelerated learning to pass PMI's PMP exam*.

https://books.google.co.uk/books/about/PMP_Exam_Prep.html?id=yKI6nQEACAAJ&redir_esc=y

Muñoz-Torres, M. J., Fernández-Izquierdo, M. ángeles, Rivera-Lirio, J. M., Ferrero-Ferrero, I., Escrig-Olmedo, E., Gisbert-Navarro, J. V., & Marullo, M. C. (2018). An assessment tool to integrate sustainability principles into the global supply chain. *Sustainability (Switzerland)*, *10*(2). https://doi.org/10.3390/su10020535

Muwazir Mukhazir, M. (2011). Corporate social responsibility in the context of financial services sector in Malaysia. *Facta Universitatis*, *8*(February 2011), 1–13. http://orca.cf.ac.uk/21878/

National, B., & Stewardship, E. (2005). 2005 Environmental Sustainability Index. *Environmental Law*, 403–409.

Nestle. (2014). *Nestle*.

Nestlé. (2015). Nestlé in society creating shared value and meeting our commitments 2015. *Global Reporting Initiative*, *Vol.1*, 1. https://doi.org/10.1111/acfi.12243

Neumayer, E. (2003). *Weak Versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*. Edward Elgar Publishing. https://books.google.com/books?hl=en&lr=&id=To3wppSlwc8C&pgis=1

Nikulina, V., Baumann, H., Simon, D., & Sprei, F. (2018). *Sustainable Transport Futures: Analysis of the Selected Methodologies Supporting the Planning Process Towards Achieving Goal 11 Sustainable Cities and Communities* (pp. 473–488). Springer, Cham. https://doi.org/10.1007/978-3-319-63007-6_29

NIST. (2015). *NIST Sustainable Manufacturing Indicators Repository (SMIR)*. http://www.mel.nist.gov/msid/SMIR/index.html

Ny, H., MacDonald, J. P., Broman, G., Yamamoto, R., & Robért, K.-H. (2008). Sustainability Constraints as System Boundaries: An Approach to Making Life-Cycle Management Strategic. *Journal of Industrial Ecology*, *10*(1–2), 61–77. https://doi.org/10.1162/108819806775545349

O'Hare, J. a. (2010). Eco-Innovation Tools for the Early Stages: An Industry-Based Investigation of Tool Customisation and Introduction. *Mechanical Engineering*, 306. http://opus.bath.ac.uk/20208/

O'Riordan, L., & Fairbrass, J. (2008). Corporate social responsibility (CSR): Models and theories in stakeholder dialogue. *Journal of Business Ethics*, *83*(4), 745–758. https://doi.org/10.1007/s10551-008-9662-y

Oecd. (2007). *World Energy Outlook 2007 : China and India Insights.* Organization for Economic Cooperation & Development. http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1927

Oecd. (2008). Measuring Sustainable Production. In *Production*. https://doi.org/10.1787/9789264044135-en

Oecd. (2009). Eco-Innovation in Industry. In *Growth Lakeland*. https://doi.org/10.1787/9789264077225-en

Oecd. (2016). *Main Science and Technology Indicators*. http://www.oecd.org/sti/msti.htm

Oke, A. E., & Aigbavboa, C. O. (2017). *Sustainable Value Management for Construction Projects*. https://doi.org/10.1007/978-3-319-54151-8

Olander, S. (2007). Stakeholder impact analysis in construction project management. *Construction Management and Economics*, *25*(3), 277–287. https://doi.org/10.1080/01446190600879125

Osiro, L., Lima-Junior, F. R., & Carpinetti, L. C. R. (2018). A group decision model based on quality function deployment and hesitant fuzzy for selecting supply chain sustainability metrics. *Journal of Cleaner Production*, *183*, 964–978. https://doi.org/10.1016/j.jclepro.2018.02.197

P&G. (2014). *At P & G , sustainability is part of everything we do .*

Paju, M., Heilala, J., Hentula, M., Heikkilä, A., Johansson, B., Leong, S., & Lyons, K. (2010). Framework and indicators for a sustainable manufacturing mapping methodology. *Proceedings - Winter Simulation Conference*, 3411–3422. https://doi.org/10.1109/WSC.2010.5679031

Paterson, D. A. P., Ijomah, W. L., & Windmill, J. F. C. (2017). End-of-life decision tool with emphasis on remanufacturing. *Journal of Cleaner Production*, *148*, 653–664. https://doi.org/10.1016/j.jclepro.2017.02.011

Pelenc, J. (2015). *Weak Sustainability versus Strong Sustainability*. *2005*, 1–4.

Pepsico. (2013). pepsico. *Chief Executive*.

Pepsico. (2016). 2025 Sustainability Agenda. *PepsiCo.*

Permatasari, P. (2006). *Based Performance Measurement & Strategic*. 41–52.

Plaza, R. (2015). *ENGAGING SUSTAINABILITY STAKEHOLDERS*.

Pohekar, S. D., & Ramachandran, M. (2004). Application of multi-criteria decision making to sustainable energy planning - A review. *Renewable and Sustainable Energy Reviews*, *8*(4), 365–381. https://doi.org/10.1016/j.rser.2003.12.007

Pope, J., Annandale, D., & Morrison-Saunders, A. (2004). Conceptualising sustainability assessment. *Environmental Impact Assessment Review*, *24*(6), 595–616. https://doi.org/10.1016/j.eiar.2004.03.001

Pounder, J. S. (1999). Organisational self-assessment in higher education: Experimenting with the competing values model and behaviourally anchored rating scales. *Research in Post-Compulsory Education*, *4*(1), 39–57. https://doi.org/10.1080/13596749900200045

Poveda, C. A., & Lipsett, M. G. (2014). An integrated approach for sustainability assessment: The Wa-Pa-Su project sustainability rating system. *International Journal of Sustainable Development and World Ecology*, *21*(1), 85–98. https://doi.org/10.1080/13504509.2013.876677

Pradella, L., & Marois, T. (2015). *Polarising development : alternatives to neoliberalism and the crisis*. Pluto Press. https://www.academia.edu/9680429

Puglieri, F. N., Ometto, A. R., Salvador, R., Barros, M. V., Piekarski, C. M., Rodrigues, I. M., & Netto, O. D. (2020). An environmental and operational analysis of quality function deployment-based methods. *Sustainability (Switzerland)*, *12*(8), 1–18. https://doi.org/10.3390/SU12083486

Rahimifard, S., Seow, Y., & Childs, T. (2010). Minimising Embodied Product Energy to support energy efficient manufacturing. *CIRP Annals*, *59*(1), 25–28. https://doi.org/10.1016/J.CIRP.2010.03.048

Rametsteiner, E., Alkan-Olsson, J., & Frederiksen, P. (2011). Sustainability indicator development-science or political negotiation? *Ecological Indicators*, *11*(1), 61–70. https://doi.org/10.1016/j.ecolind.2009.06.009

Rasheed, A., & Ion, W. (2022). A Novel Approach towards Sustainability Assessment in Manufacturing and Stakeholder’s Role. *Sustainability (Switzerland)*, *14*(6). https://doi.org/10.3390/su14063221

Rathod, G., Vinodhb, S., & Madhyasta, U. R. (2011). Integration of ECQFD and LCA for enabling sustainable product design in an electric vehicle manufacturing organisation. *International Journal of Sustainable Engineering*, *4*(3), 202–214. https://doi.org/10.1080/19397038.2010.547624

Richard M. Grinnell, Jr., Y. A. U. (2010). *Social Work Research and Evaluation: Foundations of Evidence-Based Practice*. https://books.google.co.uk/books?id=XEoq04hUpt8C&dq=Grinnell,+R.M.,+Jr.,+Unrau,+Y.A.,+2010&source=gbs_navlinks_s

Rihar, L., & Kušar, J. (2021). Implementing concurrent engineering and QFD method to achieve realization of sustainable project. *Sustainability (Switzerland)*, *13*(3), 1–28. https://doi.org/10.3390/su13031091

Robert, W., Thomas, M., & Anthony, A. (2005). *What Is Sustainable Development ?*

Romli, A. (2015). *Integrated Eco-design Decision Making for Sustainable Product Design*. *October*.

Saisana, M., & Tarantola, S. (2002). State-of-the-art Report on Current Methodologies and Practices for Composite Indicator Development. *Joint Research Centre. Italy: European Commission*, 1–72.

Sakao, T. (2007). A QFD-centred design methodology for environmentally conscious product design. *International Journal of Production Research*, *45*(18–19), 4143–4162.

https://doi.org/10.1080/00207540701450179

Sala, S., Ciuffo, B., & Nijkamp, P. (2015). A systemic framework for sustainability assessment. *Ecological Economics*, *119*, 314–325. https://doi.org/10.1016/j.ecolecon.2015.09.015

Sarl, V. G. (2015). *LCA scope and analysed system boundaries Definition of limits and functional units : LCA preparation*. *June 2013*.

Shuttleworth, M. (2008). *Chapter No. 4 Research Methodology*. https://shodhganga.inflibnet.ac.in/bitstream/10603/53269/13/13_chapter 4.pdf

Simons, D., & Mason, R. (2002). Environmental and transport supply chain evaluation with sustainable value stream mapping. *Proceedings of the 7th Logistics Research Network …*.

Singh, R. K., Murty, H. R., Gupta, S. K., & Dikshit, A. K. (2012). An overview of sustainability assessment methodologies. *Ecological Indicators*, *15*(1), 281–299. https://doi.org/10.1016/j.ecolind.2011.01.007

Sivak, M. (2009). Risk Assessment Guidance. *Forum American Bar Association*, 1–3.

Solow, R. M. (1991). *Sustainability_Economists_Perspective.Pdf*.

Souza, R. G., Rosenhead, J., Salhofer, S. P., Valle, R. A. B., & Lins, M. P. E. (2015). Definition of sustainability impact categories based on stakeholder perspectives. *Journal of Cleaner Production*, *105*, 41–51. https://doi.org/10.1016/j.jclepro.2014.09.051

Springer, S., Birch, K., & MacLeavy, J. (2016a). *The handbook of neoliberalism*. Routledge, Taylor & Francis Group. https://books.google.com/books?id=&pg=PAPA551

Springer, S., Birch, K., & MacLeavy, J. (2016b). *The handbook of neoliberalism*. Routledge. https://www.routledge.com/The-Handbook-of-Neoliberalism/Springer-Birch-MacLeavy/p/book/9781138844001

Srivastava, S. K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, *9*(1), 53–80. https://doi.org/10.1111/j.1468-2370.2007.00202.x

Stork, N. E., Boyle, T. J. B., Dale, V., Eeley, H., Finegan, B., Lawes, M., & Manokaran, N. (1997). Criteria and Indicators for Assessing the Sustainability of Forest Management : Conservation of Biodiversity. *Energy*, *62*(17), 35. https://doi.org/10.17528/cifor/000077

Swartz, S. (2016). Starting at the source: Sustainability in supply chains. *Mckinsey*, *November*, 1–13.

Tamburino, L., Bravo, G., Clough, Y., & Nicholas, K. A. (2020). From population to production: 50 years of scientific literature on how to feed the world. *Global Food Security*, *24*(December 2019). https://doi.org/10.1016/j.gfs.2019.100346

Terre Blanche, M. J. (Martin J. ., Durrheim, K., & Painter, D. (2006). *Research in practice : applied methods for the social sciences*.

Tosey, P., & Mathison, J. (2010). Neuro-linguistic programming as an innovation in education and teaching. *Innovations in Education and Teaching International*, *47*(3), 317–326. https://doi.org/10.1080/14703297.2010.498183

Toth, F. L. (1998). Integrated environmental assessment methods: Evolution and applications. *Environmental Modeling and Assessment*, *3*(3), 193–207. https://doi.org/10.1023/A:1019071008074

Trust, C. (2016). *About the Carbon Trust*. https://www.carbontrust.com/home/

Tuni, A., & Rentizelas, A. (2018). An innovative eco-intensity based method for assessing extended supply chain environmental sustainability. *International Journal of Production Economics*, *217*(September 2018), 126–142. https://doi.org/10.1016/j.ijpe.2018.08.028

UNIDO. (2014). *Inclusive and Sustainable Industrial Development*. 1–16. https://doi.org/10.4135/9781446218334.n1

Unilever. (2014). Unilever. *Building Engineer*, *82*(9), 20–21. http://www.scopus.com/inward/record.url?eid=2-s2.0-34648831927&partnerID=tZOtx3y1

United Nations. (2007). Indicators of Sustainable Development : Guidelines and Methodologies. In *New York* (Issue October). https://doi.org/10.1016/j.cirpj.2010.03.002

United Nations Environment Programme. (2011). *Bridging the emissions gap : a UNEP synthesis report.* United Nations Environment Programme. http://www.unep.org/pdf/UNEP_bridging_gap.pdf

Veleva, V., Hart, M., Greiner, T., & Crumbley, C. (2001). Indicators of sustainable production. In *Clean Technologies and Environmental Policy* (Vol. 9, Issues 3–4). https://doi.org/10.1007/s10098-003-0221-z

Venditti, R. A. (2014). *Life cycle analysis (LCA) and sustainability assessment*.

Verheem, R., & Laeven, M. (2009). *SEA for flood protection in The Netherlands – A Case Study*. *May 2002*, 20–25.

Vinodh, S., Manjunatheshwara, K. J., Karthik Sundaram, S., & Kirthivasan, V. (2017). Application of fuzzy quality function deployment for sustainable design of consumer electronics products: a case study. *Clean Technologies and Environmental Policy*, *19*(4), 1021–1030. https://doi.org/10.1007/s10098-016-1296-7

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human Domination of Earth ' s Ecosystems. *Science, New Series*, *277*(5325), 494–499. https://doi.org/00368075

Ward, H., Burger, M., Chang, Y. J., Fürstmann, P., Neugebauer, S., Radebach, A., Sproesser, G., Pittner, A., Rethmeier, M., Uhlmann, E., & Steckel, J. C. (2015). Assessing carbon dioxide emission reduction potentials of improved manufacturing processes using multiregional input output frameworks. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2016.02.062

Warwick. (2007). Product Excellence: Quality Function Deployment. *Product Excellence Using Six Sigma*. http://www2.warwick.ac.uk/fac/sci/wmg/ftmsc/modules/modulelist/peuss/slides/section_6a_qfd_notes.pdf

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, *6*(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6

William Colton. (2017). *The evolving energy mix - Energy Factor*. https://energyfactor.exxonmobil.com/perspectives/evolving-energy-mix/

Yazdani, M., Hashemkhani Zolfani, S., & Zavadskas, E. K. (2016). New integration of MCDM methods and QFD in the selection of green suppliers. *Journal of Business Economics and Management*, *17*(6), 1097–1113. https://doi.org/10.3846/16111699.2016.1165282

Young, J. M., & Solomon, M. J. (2009). How to critically appraise an article. *Nature Clinical Practice Gastroenterology and Hepatology*, *6*(2), 82–91. https://doi.org/10.1038/ncpgasthep1331

Zhang, H., & Haapala, K. R. (2015). Integrating sustainable manufacturing assessment into decision making for a production work cell. *Journal of Cleaner Production*, *105*, 52–63. https://doi.org/10.1016/j.jclepro.2014.01.038

Zhang, Y., Wang, H. P., & Zhang, C. (1999). Green QFD-II: A life cycle approach for environmentally conscious manufacturing by integrating LCA and LCC into QFD matrices. *International Journal of Production Research*, *37*(5), 1075–1091. https://doi.org/10.1080/002075499191418

Appendix

POMS2017 Conference

(Macquarie Business School Sydney, Australia)

Dec 11-13, 2017

Sustainability Performance Framework in Manufacturing (SPFM)

Track: Sustainable Operations

Aamir Rasheed [1], Dr Rentizelas Athanasios [2], Prof Bill Ion [3]

Design, Manufacture and Engineering Management, University of Strathclyde, Glasgow, UK

aamir.rasheed@strath.ac.uk

athanasios.rentizelas@strath.ac.uk

w.j.ion@strath.ac.uk

Abstract

With increasing consumer awareness and government policies to address environmental challenges and social responsibility, the manufacturing sector is under continuous pressure to adopt more sustainable operations for present and future needs. There are trends for the sustainable manufacturing and factories of the future to adapt to the markets' needs and the growing requirements for economic and ecological efficiency and corporate responsibility to address sustainability concerns.

There have been various approaches proposed to assess sustainability over the last decades. Most of these approaches are incomplete, of marginal relevance to the manufacturing environment, limit their focus on only one aspect of sustainability, or are too complicated for most organisations to implement. Numerous studies have shown a gap between the sustainability elements consumers expect and what manufacturers deliver. There is a realisation that the manufacturing sector should adopt an active approach towards sustainability assessment, capture local and global sustainability trends and address stakeholders' concerns.

This paper aims to present a sustainability performance framework in manufacturing that allows concerned stakeholders, including consumers, to select sustainability elements and

indicators using a quality function deployment-based tool (QFD). Quality function deployment has been used in the past for various applications, including to increase the performance of environmental and social-economic value-added products, services and projects. The proposed sustainability performance framework further supports selecting sustainability elements, manufacturing boundaries for assessment and relative weighting towards sustainability indicators. Combined with the scoring model, these actions can help organisations understand how manufacturing operations interact with sustainability and better allocate organisational resources to manage and improve sustainability performance.

A survey to capture stakeholder's expectations

in the Drinks and food sector

Introduction

Mr Aamir Rasheed is developing a sustainability assessment framework based on the QFD-AHP tool. It requires stakeholders' expectations for capturing and prioritising sustainability indicators list. The consumer is one of the key stakeholders and prioritises sustainability elements for the food & beverages sector.

What is the purpose of this investigation?

This survey aims to understand the stakeholders' expectations and prioritise sustainability in food & drinks manufacturing.

What will you do in the project?

In this survey, you should rate sustainability elements as significant as expected in manufacturing, mainly the food & beverage sector. The scale is 1 to 5, where one is least significant, and 5 carries maximum significance.

Manufacturing practices have an impact on sustainability on earth.

The participants asked about the sustainability elements and how they understand and rate sustainability elements in manufacturing. There is a relationship between manufacturing practices contributing to climate change, rising sea levels, and greenhouse gas emissions.

What are the potential risks to you in taking part?

Accurate information and assessment tools will help the organisation to understand and set priorities to sustainability where wrong or inaccurate information could lead to wrong sustainability assessment and organisation prioritisations.

What happens to the information in the project?

This survey does not require any confidential information, and output will be used only for educational and academic purposes.

Please mark yes and provide your email address to see the survey's outcome.

Yes	No	Email	

Researcher contact details:

Aamir Rasheed, DMEM, University of Strathclyde, Glasgow, UK

aamir.rasheed@strath.ac.uk

Survey Questionnaire

Please answer the following questions with your best understanding and rate different sustainability elements in the UK's Food & beverages sector.

Rating score scale (1 to 5)

1: Not at all important

2: Not very Important

3: Somewhat important

4: Very important

5: Most important

Q1. Do you understand the term 'Sustainability' and Sustainable manufacturing? (Please circle the answer)

Yes	No

Q2. Do you agree that sustainability is a matter of concern and relevant in manufacturing? (Please circle the answer)

Yes	No

Q3. Please rate the following environmental sustainability elements. If you consider another sustainability aspect, write down in comments with reasoning.

(Where 1 is minimum, and 5 has maximum importance).

Emissions (1-5)	Energy Consumption (1-5)	Water Utilisation (1-5)	Biodiversity (1-5)	Materials Consumption (1-5)

Comments:

Q4. Please rate the following social sustainability elements. If you consider another sustainability aspect, write down in comments with reasoning.

(Where 1 is minimum, and 5 has maximum importance)

Consumer responsibility (1-5)	Employee satisfaction survey (1-5)	Equal Opportunity & Gender pay gap (1-5)	Health and Safety Conditions (1-5)

Comments:

Q5. Please rate the following Performance Management sustainability elements. If you consider another aspect, then write down in comments with reasoning.

(Where 1 is minimum, and 5 has maximum importance).

Conformance (1-5)	Program & Policy (1-5)

Comments:

Evaluation of "Sustainability score system in manufacturing" (3SM)

Participant Name:

Participant experience (years):

Evaluating the effectiveness of model and relevancy in the manufacturing environment

Please rate the following aspects of the 3SM by circling your response. If you have specific comments to add, please write them in the comments section

1. Ease of Understanding of model considering manufacturing application

Poor	Fair	No Opinion	Good	Excellent
Comments:				

2. Help understand the stakeholders' requirements and aggregate their feedback in sustainability assessment.

Poor	Fair	No Opinion	Good	Excellent
Comments:				

3. Validity and applicability of the model in a manufacturing environment.

Poor	Fair	No Opinion	Good	Excellent
Comments:				

4. How do you rate the utility of the model in a manufacturing environment?

Poor	Fair	No Opinion	Good	Excellent
Comments:				

5. Feedback about the model.

Comments:

Change request form for 3SM

Change requested by:
Date:
Reason for change:
Impact on framework quality:
The time required to make the change:
Change Authorised / Agreed:
Completion date:
Framework updated:
Comments:

SUSTAINABILITY INDICATORS DATA BANK

Providing a sustainability data bank of indicators provides a comprehensive sustainability indicators database. Establishing a centralise sustainability indicators database will benefit the manufacturing organisations to choose applicable indicators

- Grouping and categorised sustainability indicators set based on relevance and application
- The search capability of relative sustainability indicators database
- A comprehensive database of published sustainability indicators

The following table provides the various published sustainable manufacturing indicators repository indicators database published and publicly available.

Sustainable manufacturing Indicators repository available indicators database

Various Sustainability Indicators & Metrics		
Indicator Set	Component	Reference
Global Report Initiative (GRI)	70 Indicators	(Initiative, 2016)
Dow Jones Sustainability Index (DJSI)	12 criteria based single indicator	(Jones, 2016)
2005 Environment sustainability indicators	76 building block	(Etsy & Andonov, 2005)
2006 Environment performance Indicators	19 indicators	(DEFRA, 2006)
United Nations Committee on sustainable development indicators	50 Indicator	(Sands, 1992)
OECD core indicators	46 Indicator	(OECD, 2008)
Indicator database	409 indicators	(Data, 2016)
Ford product sustainability Index	8 Indicator	(Schmidt, 2007)
GM metrics for sustainable manufacturing	46 Metrics	(Dreher, Lawler, Stewart, Strasorier, & Thorne, 2009)
ISO – 14031 environment performance evaluation	155 example indicators	(ISO-14031, 2013)
Wal-Mart sustainability product index	15 questions	(Walmart, 2009)
Environment Indicators for the European Union	60 Indicators	(EEA, 2015)
Lowell Center for Sustainable Production (LCSP) Model	22 indicators	(Veleva et al., 2001)

NIST Manufacturing Indicators	110 indicators	(US Department of Commerce, 2015)
CSD Sustainable Development	44 Indicators	(United, Division, Development, Commission, & Indicators, 2001)
2016 Environmental Performance Index (2016 EPI)	22 Indicators	(EPI, 2016)

Most manufacturing organisations use their customised indicators suited to business nature and practice. Table 2-1 provides a comprehensively sustainable manufacturing indicators data bank to decide and select relevant sustainability indicators.

Indicators name	Explanation	Unit	References	ID
Wastewater produced	Amount of wastewater discharged	The volume of total discharge water from the organisation or process	GRI emissions GM-MSM-waste water management ISO 14031-operational performance indicators: effluent to land/water	Env-1
Treated/non-treated wastewater produced within premises	The proportion of treated and non-treated water either by an organisation or municipal	The ratio of treated and untreated water discharge to the sewerage	CSD-fresh water quality EPI EU Urban environment EEA CSI-water	Env-2
Total waste produced in premises	The total amount of waste generated by an organisation or produced during the process	Kilograms of waste generated	GRI-Emissions, effluents, and waste DJSI-Environment performance EPO EU-Waste OECD-Pollution issues: waste generation; EEA CSI-Waste	Env-3
Reusable waste in results of processes	The amount of waste generated by the organisation can use in other processes/operations	Kilograms of reusable waste ratio to total waste	ISO14031-operational performance indicators: waste	Env-4
Recyclable waste produced	The amount of waste generated by the organisation can use in other processes/operations	Kilograms of recyclable waste ratio to total waste	CSD – waste generated and management ISO 14031- Operational performance indicators: wasters; EPI EU – Waste ESI- reducing environment stresses: reducing waste and consumption pressure	Env-5

			GM MSM- Waste Management	
Remanufactured waste produced	Amount of waste that is remanufactured in the production process for an organisation	Kilograms of manufacturable waste ratio to total waste	NIST- Sustainable manufacturing indicator	Env-6
Disposal Waste	The amount of waste produced by an organisation or during processes will use by landfill or non-recycling	Kilograms of disposal waste ratio to total waste	CSD: waste generated and management GM MSM-Waste Management; ISO 14031-Operational performance indicators: Effluents to land/water; EPI EU-Urban environmental problems; EPI EU-Waste	Env-7
Waste removal efficiency unit	The ratio of waste removed during processing versus total waste removed	Kilograms of the waste removed ratio	GM MSM-Waste Management	Env-8
Waste energy emission	All forms of energy, vibrations emissions from organisation or processes	The energy released from organisation or processes in joules	CSI-Energy	Env-9

Air emissions	Amount of gas emitted to the environment by an organisation or processes	The volume of total gas discharged by an organisation or process in meter cubic	NIST- Sustainable manufacturing indicator	Env-10
Lead (Pb) used	Amount of hazardous materials used by an organisation or process	Kilograms of hazardous material used in organisation or processes	ISO 14031-Operational performance indicators: Materials; ESI-Global Stewardship: Reducing Transboundary Environmental Pressures; EPI EU-Water pollution and water resource	Env-11
Mercury (Hg) used	Amount of hazardous materials used by an organisation or process	Kilograms of hazardous material used in organisation or processes	ISO 14031-Operational performance indicators: Materials; ESI-Global Stewardship: Reducing Transboundary Environmental Pressures; EPI EU-Water pollution and water resource	Env-12
Hexavalent Chromium (Cr6+) used	Amount of hazardous materials used by an organisation or process	Kilograms of hazardous material used in organisation or processes	ISO 14031-Operational performance indicators: Materials; ESI-Global Stewardship: Reducing Transboundary Environmental Pressures; EPI EU-Water pollution and water resource	Env-13

Cadmium (Cd) used	Amount of hazardous materials used by an organisation or process	Kilograms of hazardous material used in organisation or processes	ISO 14031-Operational performance indicators: Materials; ESI-Global Stewardship: Reducing Transboundary Environmental Pressures; EPI EU-Water pollution and water resource	Env-14
Polybrominated biphenyl flame retardants (PBB) used	Amount of hazardous materials used by an organisation or process	Kilograms of hazardous material used in organisation or processes	ISO 14031-Operational performance indicators: Materials; ESI-Global Stewardship: Reducing Transboundary Environmental Pressures; EPI EU-Water pollution and water resource	Env-15
Polybrominated diphenyl ether flame retardants (PBDE) used	Amount of hazardous materials used by an organisation or process	Kilograms of hazardous material used in organisation or processes	ISO 14031-Operational performance indicators: Materials; ESI-Global Stewardship: Reducing Transboundary Environmental Pressures; EPI EU-Water pollution and water resources	Env-16
Eco-toxic substance effluent	Amount of hazardous materials used by an	Kilograms of hazardous material used in organisation or processes	GRI-Emissions, effluents, and waste;	Env-17

	organisation or process		ESI-Reducing Environmental Stresses: Reducing Waste & Consumption Pressure; CSD-Consumption and production patterns: Waste generation and management; GM MSM-Waste Management; ISO 14031-Operational performance indicators: Wastes; ISO 14031-Operation performance indicators: Other emissions; EPI EU-Dispersion of toxic substances; EPI EU-Waste; OECD-Pollution Issues: Waste Generation	
Number of WEEE-related registrations	WEEE-related registrations per country and scheme for a product or an organisation	Number of WEEE-related registrations per country and scheme for a product or an organisation	WEEE	Env-18
Chemical Spills	Total number and volume of significant spills at an organisation's facility or from a process	Number and volume of significant spills at an organisation	GRI-Emissions, effluents, and waste	Env-19

Eco-toxic substances emission	Specific eco-toxic substances emitted by an organisation's facility, process, and product. Includes: persistent organic pollutants (POPs)	Kilograms or per cent of eco-toxic substances emitted categorised by type for an organisation's facility, process, or product	ISO 14031-Environmental condition indicators: Air; EPI EU-Dispersion of toxic substances	Env-20
CO_2 emissions	Specific GHGs emitted by an organisation's facility, process, and product. CO_2, CH_4, N_2O, CFCs, NO_x, SO_x, etc.	Kilograms or per cent of GHGs emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; EPI-Ecosystem Vitality: Air Pollution (effects on ecosystems); EPI-Ecosystem Vitality: Climate Change; DJSI-Environmental Performance (Eco-Efficiency); ESI-Environmental System: Air Quality; ESI-Reducing Environmental Stresses: Reducing Air Pollution; ESI-Global Stewardship: Greenhouse Gas Emissions; CSD-Atmosphere: Climate change; Ford PSI-Emissions, effluents, and waste; GM MSM-Environmental Impacts; WSPI-Energy and Climate: Reducing Energy Costs and Greenhouse Gas Emissions;	Env-21

			ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution; EPI EU-Climate Change; OECD-Pollution Issues: Climate Change; CSI-Climate Change	
CH4	Specific GHGs emitted by an organisation's facility, process, and product. CO2, CH4, N2O, CFCs, NOx, SOx, etc.	Kilograms or per cent of GHGs emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; EPI-Ecosystem Vitality: Air Pollution (effects on ecosystems); EPI-Ecosystem Vitality: Climate Change; DJSI-Environmental Performance (Eco-Efficiency); ESI-Environmental System: Air Quality; ESI-Reducing Environmental Stresses: Reducing Air Pollution; ESI-Global Stewardship: Greenhouse Gas Emissions; CSD-Atmosphere: Climate change; Ford PSI-Emissions, effluents, and waste; GM MSM-Environmental Impacts;	Env-22

			WSPI-Energy and Climate: Reducing Energy Costs and Greenhouse Gas Emissions; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution; EPI EU-Climate Change; OECD-Pollution Issues: Climate Change; CSI-Climate Change	
N_2O emissions	Specific GHGs emitted by an organisation's facility, process, and product. Includes: CO_2, CH_4, N_2O, CFCs, NO_x, SO_x, etc	Kilograms or per cent of GHGs emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; EPI-Ecosystem Vitality: Air Pollution (effects on ecosystems); EPI-Ecosystem Vitality: Climate Change; DJSI-Environmental Performance (Eco-Efficiency); ESI-Environmental System: Air Quality; ESI-Reducing Environmental Stresses: Reducing Air Pollution; ESI-Global Stewardship: Greenhouse Gas Emissions; CSD-Atmosphere: Climate change; Ford PSI-Emissions, effluents, and waste;	Env-23

			GM MSM-Environmental Impacts; WSPI-Energy and Climate: Reducing Energy Costs and Greenhouse Gas Emissions; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution; EPI EU-Climate Change; OECD-Pollution Issues: Climate Change; CSI-Climate Change	
CFCs emissions	Specific GHGs emitted by an organisation's facility, process, and product. CO_2, CH_4, N_2O, CFCs, NO_x, SO_x, etc.	Kilograms or per cent of GHGs emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; EPI-Ecosystem Vitality: Air Pollution (effects on ecosystems); EPI-Ecosystem Vitality: Climate Change; DJSI-Environmental Performance (Eco-Efficiency); ESI-Environmental System: Air Quality; ESI-Reducing Environmental Stresses: Reducing Air Pollution; ESI-Global Stewardship: Greenhouse Gas Emissions; CSD-Atmosphere: Climate change; Ford PSI-Emissions, effluents, and waste;	Env-24

			GM MSM-Environmental Impacts; WSPI-Energy and Climate: Reducing Energy Costs and Greenhouse Gas Emissions; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution; EPI EU-Climate Change; OECD-Pollution Issues: Climate Change; CSI-Climate Change	
NOx emissions	Specific GHGs emitted by an organisation's facility, process, and product. Includes: CO2, CH4, N2O, CFCs, NOx, SOx, etc	Kilograms or per cent of GHGs emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; EPI-Ecosystem Vitality: Air Pollution (effects on ecosystems); EPI-Ecosystem Vitality: Climate Change; DJSI-Environmental Performance (Eco-Efficiency); ESI-Environmental System: Air Quality; ESI-Reducing Environmental Stresses: Reducing Air Pollution; ESI-Global Stewardship: Greenhouse Gas Emissions; CSD-Atmosphere: Climate change; Ford PSI-Emissions, effluents, and waste; GM MSM-Environmental Impacts; WSPI-Energy and	Env-25

			Climate: Reducing Energy Costs and Greenhouse Gas Emissions; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution; EPI EU-Climate Change; OECD-Pollution Issues: Climate Change; CSI-Climate Change	
SOx emissions	Specific GHGs emitted by an organisation's facility, process, and product. CO2, CH4, N2O, CFCs, NOx, SOx, etc.	Kilograms or per cent of GHGs emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; EPI-Ecosystem Vitality: Air Pollution (effects on ecosystems); EPI-Ecosystem Vitality: Climate Change; DJSI-Environmental Performance (Eco-Efficiency); ESI-Environmental System: Air Quality; ESI-Reducing Environmental Stresses: Reducing Air Pollution; ESI-Global Stewardship: Greenhouse Gas Emissions; CSD-Atmosphere: Climate change; Ford PSI-Emissions, effluents, and waste;	Env-26

			GM MSM-Environmental Impacts; WSPI-Energy and Climate: Reducing Energy Costs and Greenhouse Gas Emissions; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution; EPI EU-Climate Change; OECD-Pollution Issues: Climate Change; CSI-Climate Change	
BFCs emissions	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc	Kilograms or per cent of ozone-depleting substances emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; ESI-Reducing Environmental Stresses: Reducing Air Pollution; CSD-Atmosphere: Ozone layer depletion; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution, EPI EU-Ozone layer depletion; OECD-Pollution Issues: Climate Change: OECD-Pollution Issues: Ozone layer;	Env-27

			EEA CSI-Air pollution and ozone depletion	
HCFCs emissions	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc.	Kilograms or per cent of ozone-depleting substances emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; ESI-Reducing Environmental Stresses: Reducing Air Pollution; CSD-Atmosphere: Ozone layer depletion; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution, EPI EU-Ozone layer depletion; OECD-Pollution Issues: Climate Change; OECD-Pollution Issues: Ozone layer; EEA CSI-Air pollution and ozone depletion	Env-28
CFC-x emissions	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc	Kilograms or per cent of ozone-depleting substances emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; ESI-Reducing Environmental Stresses: Reducing Air Pollution; CSD-Atmosphere: Ozone layer depletion;	Env-29

			ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution, EPI EU-Ozone layer depletion; OECD-Pollution Issues: Climate Change; OECD-Pollution Issues: Ozone layer; EEA CSI-Air pollution and ozone depletion	
CH3Br emissions	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc.	Kilograms or per cent of ozone-depleting substances emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; ESI-Reducing Environmental Stresses: Reducing Air Pollution; CSD-Atmosphere: Ozone layer depletion; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution, EPI EU-Ozone layer depletion; OECD-Pollution Issues: Climate Change; OECD-Pollution Issues: Ozone layer; EEA CSI-Air pollution and ozone depletion	Env-30

VOCs emissions	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc.	Kilograms or per cent of ozone-depleting substances emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; ESI-Reducing Environmental Stresses: Reducing Air Pollution; CSD-Atmosphere: Ozone layer depletion; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution, EPI EU-Ozone layer depletion; OECD-Pollution Issues: Climate Change; OECD-Pollution Issues: Ozone layer; EEA CSI-Air pollution and ozone depletion	Env-31
Chlorinated carbons emissions	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc.	Kilograms or per cent of ozone-depleting substances emitted are categorised by type for an organisation's facility, process, or product	GRI-Emissions, effluents, and waste; ESI-Reducing Environmental Stresses: Reducing Air Pollution; CSD-Atmosphere: Ozone layer depletion; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution, EPI EU-Ozone layer depletion;	Env-32

			OECD-Pollution Issues: Climate Change; OECD-Pollution Issues: Ozone layer; EEA CSI-Air pollution and ozone depletion	
SF6 emissions	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc.	Specific ozone-depleting substances emitted by an organisation's facility, process, and product. Includes: BFCs, HCFCs, CFC-x, CH3Br, VOCs, chlorinated carbons, SF6, etc.	GRI-Emissions, effluents, and waste; ESI-Reducing Environmental Stresses: Reducing Air Pollution; CSD-Atmosphere: Ozone layer depletion; ISO 14031-Operational performance indicators: Emissions; EPI EU-Air pollution, EPI EU-Ozone layer depletion; OECD-Pollution Issues: Climate Change; OECD-Pollution Issues: Ozone layer; EEA CSI-Air pollution and ozone depletion	Env-33
Noise emission	Noise and vibrations emitted from an organisation's facility, process, and product	Decibels of noise emission from an organisations facility, process, and product	Ford PSI-Environmental Health: Air Pollution (effects on humans);	Env-34

			ISO 14031-Operation performance indicators: Other emissions; EPI EU-Urban environmental problems;	
Acidification substances	Emissions of specific acidifying substances from an organisation's facility or process	The weight of or per cent of acidifying substances emitted from an organisations facility per organisation, process, product	ESI-Reducing Environmental Stresses: Reducing Ecosystem Stress; OECD-Pollution Issues: Waste Generation; CSI-Waste	Env-35
Air quality	Within and in surrounding areas of an organisation's facility, the air quality includes smog, visibility, odour, GHG concentration, pollutant concentration, etc.	Values for given air quality indicators include smog, visibility, odour, GHG concentration, pollutant concentration	GRI-Transport; EPI-Environmental Health: Air Pollution (effects on humans); EPI-Ecosystem Vitality: Air Pollution (effects on ecosystems); ESI-Environmental Systems: Air Quality; CSD-Atmosphere: Air quality; ISO 14031-Environmental condition	Env36
Particulate emission	Emissions of small particles by an organization's facility, process, and product	Kilograms of fine particulates in the emitted air from an organisation's facility, process, or product	EPI EU-Air pollution; CSI-Air pollution and ozone depletion	Env-37

Specific material used	Amount and type of materials used by an organisation, process, and product	Kilograms and per cent of specific materials used by an organisation, process, or product categorised by type	GRI-Materials; GM MSM-Manufacturing Cost; ISO 14031-Operational performance indicators: Materials	Env-38
Material intensity	The ratio of the number of materials needed for an organisation, process, or product to the number of materials used by an organisation, process, or product	The ratio of the number of materials needed for an organisation, process, or product to the number of materials used by an organisation, process, or product	CSD-Consumption and production patterns: Material consumption	Env-39
The specific virgin material used	Amount and type of virgin materials used by an organisation, process, and product	Kilograms and per cent of specific virgin materials used by an organisation, process, or product categorised by type	GRI-Materials; Ford PSI-Materials; ISO 14031-Operational performance indicators: Materials; ISO 14031-Operational performance indicators: Products	Env-40
The specific reused material used	Amount and type of reused materials used by an organisation, process, and product and the amount of material within a	Kilograms and per cent of specific reused materials used by an organisation, process, or product categorised by type	Ford PSI-Materials; ISO 14031-Operational performance indicators: Materials; ISO 14031-	Env-41

	process or product that can be reused		Operational performance indicators: Products	
The specific repurposed material used for a similar function	Materials or components reused for a similar function as was its original intent	Kilograms and per cent of specific materials were reused for a similar function as was its original intent	NIST Sustainable manufacturing indicators	Env-42
Specific repurposed material for a different function	Materials or components reused for a different function from their original intent	Kilograms and per cent of specific materials reused for a different function from its original intent	NIST Sustainable manufacturing indicators	Env-43
The specific remanufactured material used	Materials or components remanufactured and reused	Kilograms and per cent of specific materials or components remanufactured and reused	NIST Sustainable manufacturing indicators	Env-44
Fluid consumption	Amount of extra fluids used by an organisation or process, including cleaners, lubricants, oils, coolants, etc.	Volume or dollar amount of auxiliary fluids used by an organisation or process	ISO 14031-Operational performance indicators: Services provided by the organisation	Env-45
Recyclable and reusable materials used by contracted service providers	Amount of recyclable and reusable materials used by contracted service providers	Kilograms or per cent of materials used by a contracted service provider that are reused and recycled	ISO 14031-Operational performance indicators: Services supporting the organisation's operations	Env-46
Reclaimed packaging	Generation, disposal, and recycling of packaging waste for a product	Kilograms or per cent of packaging materials that are reclaimed and recycled	GRI-Products and Services; ISO 14031-Operational performance indicators: Materials;	Env-47

			EEA CSI-Waste	
After-sales servicing materials	The number of materials used during after-sales servicing of products	Kilograms or dollar amount of materials used for after-sales servicing of products per product	ISO 14031-Operational performance indicators: Services provided by the organisation	Env-48
Energy consumption	Amount of energy consumed by an organisation, process, or product. Source and type specify energy	Energy measure or dollar amount of consumed energy directly attributable to the manufacturing process and product use categorised by type	GRI-Energy; DJSI-Environmental Performance (Eco-Efficiency); CSD-Consumption and production patterns: Energy use; GM MSM-Energy Consumption; ISO 14031-Operational performance indicators: Energy; ISO 14031-Operational performance indicators: Products; EPI EU-Air pollution; EPI EU-Resource depletion; EPI EU-Urban environmental problems; EEA CSI-Energy	Env-49
Energy intensity	The ratio of the energy used by an organisation or process to the energy available for an organisation or process	The ratio of the energy used by an organisation or process to the energy available for an organisation or process	CSD-Consumption and production patterns: Energy use;	Env-50

			CSD-Consumption and product patterns: Transportation; OECD-Pollution Issues: Climate Change; OECD-Natural Resources & Assets: Energy resources: Climate Change; EEA CSI-Energy	
Specific energy consumption (type)	Amount of energy consumed by an organisation, process, or product by type and source	Amount of energy consumed in energy measure or dollar amount by an organisation, process, or product categorised by type/source	ISO 14031-Operational performance indicators: Energy	Env-51
Indirect energy consumption	Amount of energy consumed that is not directly attributed to the manufacturing process. Source and type specify energy	Energy measure or dollar amount of consumed energy for indirect operations not attributed to the manufacturing process categorised by type	GRI-Energy	Env-52
Non-renewable energy consumption	Amount of energy consumed by an organisation, process, or product categorised by non-renewable sources (i.e. coal, crude oil, petroleum products, gas, nuclear, etc.)	Energy measure or dollar amount of consumed energy that is non-renewable categorised by type/source	ESI-Reducing Environmental Stresses: Reducing Air Pollution; ISO 14031-Operational performance indicators: Physical facilities and equipment; ISO 14031-Operational performance indicators: Services provided by the organisation; ISO 14031-	Env-53

			Operational performance indicators: Supply and delivery; EPI EU-Resource depletion; EPI EU-Air pollution; GM MSM-Energy Consumption	
Renewable energy consumption	Amount of energy consumed by an organisation, process, or product categorised by renewable sources (i.e. hydropower, wind, solar, tide and wave, biomass, etc.)	Energy measure or dollar amount of consumed energy that is renewably categorised by type/source	ESI-Social and Institutional Capacity: Eco-Efficiency; EEA CSI-Energy	Env-54
The share of renewable energy sources in total energy use	The ratio of total primary energy supplied or consumed by an organisation, process, or product to the renewable energy source used by an organisation, process, or product	The ratio of total primary energy supplied or consumed by an organisation, process, or product to the renewable energy source used by an organisation, process, or product	CSD-Consumption and production patterns: Energy use; OECD-Natural Resources & Assets: Energy resources: Socio-economic and general indicators	Env-55
Renewable energy generated	Amount of energy generated by an organisation classified as renewable (i.e. hydropower, wind, solar, tide and wave, biomass, etc.)	Amount of energy generated in energy measure or dollar amount by an organisation that is renewably categorised by type/source	GM MSM-Environmental Impacts; EEA CSI-Energy	Env-56
By-product/process	Amount of energy generated by an	The quantity of energy generated in energy		Env-57

stream energy generated	organisation through by-products of process streams	measure or dollar amount by by-products of process streams for an organisation or process	Ford PSI-Product Responsibility: Marketing Communications; ISO 14031-Operational performance indicators: Energy	
Amount of (heat) energy recaptured	The rate of energy recaptured by an organisation, process, or product	The rate of energy recaptured by an organisation, process, or product	GM MSM-Energy Consumption	Env-58
Saved energy	Amount of energy saved by an organisation, process, or product due to an implemented improvement in efficiency or conservation	Amount of energy saved in energy measure or dollar amount due to efficiency or conservation improvements	GRI-Energy; GM MSM-Manufacturing Cost; ISO 14031-Operational performance indicators: Energy	Env-59
The rate of internal recycling/heat recapturing			GM MSM	Env-60
Energy-efficient initiatives	Initiatives to provide or create energy-efficient processes and products implemented by an organisation and the impacts of these initiatives. Directly related to a manufacturing process and product	An organisation implements some energy-efficiency improvements and the energy saved from these improvements. Dollar amount saved from energy-efficiency improvements for a manufacturing process and organisation	GRI-Energy; GM MSM-Energy Consumption	Env-61
	Initiatives to provide or create energy-efficient	An organisation implements some indirect	GRI-Energy	Env-62

Energy-efficient initiatives (Indirect energy)	processes and products implemented by an organisation and the impacts of these initiatives. Indirect activities related to the manufacturing process	energy-efficiency improvements and the energy saved from these improvements. Dollar amount saved from indirect energy-efficiency improvements		
Energy efficiency	The ratio of the actual energy consumed by an organisation, process, or product to the theoretical energy needed for the organisation, process, or product	The ratio of the actual energy consumed by an organisation, process, or product to the theoretical energy needed for the organisation, process, or product	ESI-Social and Institutional Capacity: Eco-Efficiency; GM MSM-Energy Consumption	Env-63
Water used by the source	Total water used by an organisation, process, or product categorised by type/source	Volume and per cent of water used by an organisation, process, or process categorised by type/source	GRI-Water; DJSI-Environmental Performance (Eco-Efficiency); CSD-Freshwater: Water quantity; W SPI-Material Efficiency: Reducing Waste and Enhancing Quality; ISO 14031-Operational performance indicators: Materials; EPI EU-Resource depletion; EEA CSI-Water	Env-64
Water availability	The ratio of the water used for the production process or by an organisation to	The ratio of the volume of water used for a production process or organisation to the	EPI-Ecosystem Vitality: Water (effects on ecosystems);	Env-65

	the available water source	volume of the water source	ESI-Environmental Systems: Water Quantity; ESI-Reducing Environmental Stresses: Reducing Water Stress; CSD-Freshwater: Water quantity; GM MSM-Environmental Impacts; ISO 14031-Environmental condition indicators: Water; EPI EU-Water pollution and water resources; OECD-Natural Resources & Assets: Freshwater resources	
Recycled water used	Wastewater that is treated and reused within an organisation or a manufacturing process	Volume or per cent of water recycled and used, specified by the level of treatment (primary, secondary or tertiary)	GRI-Water; ISO 14031-Operational performance indicators: Materials; EPI EU-Water pollution and water resources	Env-66
Intake water quality	Amount of contaminants and nutrients within intake water supply and groundwater. Includes coliform bacteria, nutrients, pollutants, oxygen, phosphorus, suspended solids	The proportion of contaminants/nutrients per litter of intake water at a given point in time. Values of typical water quality indicators for intake water	ISO 14031-Environmental Condition Indicators: Water; EEA CSI-Water;	Env-67

			GM MSM-Environmental Impacts; 2005 ESI-Environmental Systems: Water Quality	
Land used	Land used by an organisation's facility is categorised into fertile and non-fertile areas	Square feet of an organisations facility categorised by fertile and non-fertile areas	ESI-Social Institutional Capacity: Environmental Governance; CSD-Land: Land use and status; ISO 14031-Operational performance indicators: Physical facilities and equipment; EEA CSI-Biodiversity; EEA CSI-Terrestrial	Env-68
Land quality	Waste effects on land quality are indicated by surface integrity, soil nutrients and contaminants, non-fertile land, salinised areas, etc.	Values for given land quality indicators of surrounding lands of an organisation's facility, including surface integrity, soil nutrients and contaminants, non-fertile land, salinised land areas, etc.	ESI-Reducing Environmental Stresses: Natural Resource Management; CSD-Land: Desertification; CSD-Land: Land use and status; ISO 14013-Operational performance indicators: Physical facilities and equipment; ISO 14031-Environmental condition indicators: Land; ISO 14031-Environmental condition indicators: Flora; ISO 14031-Environmental condition indicators: Aesthetics, heritage and culture;	Env-69

			EPI EU-Resource depletion; EPI EU-Dispersion of toxic substances; EPI EU-Urban environmental problems; EPI EU-Water pollution and water resources; OECD-Pollution Issues: Waste Generation; OECD-Natural Resources & Assets: Forest resources	
Surrounding building quality	Waste effects on the surface integrity of surrounding builds and places of importance	Qualitative	ISO 14031-Environmental condition indicators: Aesthetics, heritage and culture	Env-70
Surrounding protected lands	Areas protected the surrounding facility and rehabilitated in surrounding areas of a facility	The land area of protected lands surrounding an organisation's facility	ISO 14031-Environmental condition indicators: Land	Env-71
Water quality	Waste effects on water and air quality are indicated by temperature, turbidity, eutrophication, nutrient pollution, acidification, salinisation, BOD measure, contaminants, pH level, etc.	Values of typical water quality indicators for an organisation's or process' outgoing water	OECD-Pollution issues: Waste generation; GRI-Emissions, effluents, and waste; EPI-Ecosystem Vitality: Water (effects on ecosystems); CSD-Freshwater: Water quality; GM MSM-Environmental Impacts;	Env-72

			ISO 14031-Environmental condition indicators: Water; EPI EU-Marine environment and coastal zones; EPI EU-Water pollution and water resources; OECD-Pollution Issues: Freshwater quality: Eutrophication; OECD-Pollution Issues: Freshwater quality: Acidification	
Biodiversity management	The effectiveness with which protected areas are being managed based on information about the context, planning and design, resource inputs, management processes, delivery of goods and services, and conservation outcomes of protected areas	Qualitative	GRI-Biodiversity; CSD-Biodiversity: Ecosystem	Env-73
Natural habitat quality	Policies to conserve and protect surrounding natural habitats and the impacts of those policies	Qualitative	ESI-Ecosystem Vitality: Productive Natural Resources: Forestry; DJSIIndustry-specific criteria; ESI-Reducing Environmental Stresses: Reducing Ecosystem Stress; CSD-Land: Forests;	Env-74

			EPI EU-Loss of biodiversity; OECD-Natural Resources & Assets: Biodiversity	
Habitat management	The effectiveness with which habitats are protected or restored, especially forests and sustainable forests	Qualitative	GRI-Biodiversity; ESI-Reducing Environmental Stresses: Natural Resource Management; CSD-Oceans, seas and coasts: Coastal zone	Env-75

Indicators name	Explanation	Unit	References	ID
Revenue	Revenue attributable to manufacturing a product	Dollar amount	GRI; ISO 41031	Eco-1
Profits generated	Total net profits for an organisation or product	The dollar value of profits generated by an organisation or product	UN-CSD	Eco-2
Material acquisition costs	Costs for acquiring materials used within the manufacturing process for a product or an organisation	The dollar amount for acquiring materials used within the manufacturing process for a product or an organisation	NIST Sustainability Manufacturing Indicator	Eco-3
Energy costs	Cost for energy used in the production process for an organisation or a product	The dollar amount for energy used in the production process for an organisation or a product	GM; ISO 14031	Eco-4
Tooling costs	Costs for tooling, including fixtures and jigs used during the manufacturing process for an organisation or product	The dollar amount for tooling, including fixtures and jigs used during the manufacturing process for an organisation or product	GM; ISO 14031	Eco-5
Labour costs	Costs of labour (specified by indirect and direct) used during the manufacturing process for an organisation or product	The dollar amount of labour (specified by indirect and direct) used during the manufacturing process for an organisation or product	GM; ISO 14031	Eco-6
Waste treatment costs	Costs for waste treatment processes (including separation and disposal of hazardous materials, wastewater treatment, etc.) used during the manufacturing process for an organisation or a product	The dollar amount of waste treatment processes (including separation and disposal of hazardous materials, wastewater treatment, etc.) used during the manufacturing process for an organisation or a product	GM; ISO 14031	Eco-7
Packaging costs	Costs for packaging process (including materials and reclamation)of a product or total packaging cost for an organisation	The dollar amount for the packaging process (including materials and reclamation) of a product or total packaging cost for an organisation	GM; ISO 14031	Eco-8

Delivery costs	Costs for transportation of product to the customer including fuel costs, labour costs, and equipment costs	The dollar amount for transportation of product to the customer including fuel costs, labour costs, and equipment costs	GM; ISO 14031	Eco-9
Storage costs	Costs for storage of product for an organisation	The dollar amount for storage of product per product or total for an organisation	GM; ISO 14031	Eco-10
Brand management costs	Investments and expenditures in advertising, marketing, and branding of a product or technology	Dollar amount or per cent of investments in marketing and advertising per an organisation or product	GM; ISO 14031	Eco-11
Responsibility, risk & crisis management	The cost associated with managing employee responsibilities in reporting or assessing risks and crisis programs for an organisation	The dollar amount for managing employee responsibilities in reporting or assessing risks and crisis programs for an organisation	DJSI; GRI	Eco-12
Employment costs and employee benefits	Costs and benefits afforded an organisation in hiring and retaining personnel	Dollar amount afforded to an organisation for hiring and retaining employees	DJSI; GRI	Eco-13
Environmental protection expenditures	Expenditures in maintaining environmentally protected areas, ecosystems, and habitats. Includes: expenditures for air emission, water effluent treatments, solid wastes, and carbon credit or certified emission reductions (CERs) issued by Clean Development Mechanism (CDM)	Dollar amount or per cent of expenditures for maintaining environmental protection goals per an organisation	DJSI; GRI	Eco-14
Use energy costs	Cost for energy used during the use phase of a product. Includes fuel costs, electricity costs, etc.	The dollar amount for energy used during the use phase of a product per product	Ford PSI;	Eco-14

User taxation	Costs of taxes accrued for a product during its use-phase life	The dollar amount of taxes accrued for a product during its use-phase life	Ford PSI;	Eco-15
Recycling costs for WEEE	The cost to recycle a product or costs associated with recycling for an organisation	The dollar value of recycling costs for a product or dollar value of total recycling costs for an organisation	WEEE	Eco-16
(Labor) Productivity	Output for a given process per unit labour required. Labour required can account for value-added activities, as well as non-value-added activities.	A ratio value of actual labours hours to planned labour hours for performing an operation or manufacturing a product	UN CSD	Eco-17
Innovation & R/D investments	Investments and expenditures in scientific research and experimental development (R&D) for future innovative products and technologies	Dollar amount or per cent of R&D funds for the development of innovative technologies per product or organisation	DJSI	Eco-18
Charitable investments	Investments in non-profit organisations and general charity organisations for an organisation	The dollar amount of investments in non-profit organisations and general charity organisations for an organisation	NIST Sustainability Manufacturing Indicator	Eco-19
Investments and impacts of community development	Investments, expenditures, and financial progress of community development activities per job creation, infrastructure development, technology transfer, and social capital	The dollar value of investments, expenditures, and financial progress of community development activities per job creation, infrastructure development, technology transfer, and social capital	GRI	Eco-20
Renewable energies investments	Investment in renewable energy specifically applied to an organisation's operations	Dollar amount or per cent of investments for renewable energies, emission reductions, and clean development per an organisation	DJSI	Eco-21
Energy efficiency investments	Investments and expenditures in energy efficiency instruments and initiatives	Dollar amount or per cent of investments for energy efficiency improvements per organisation or product		Eco-22

Indicators name	Explanation	Unit	References	ID
Recordable injury rate	Accidents requiring first aid	Number or per cent of accidents requiring first aid	GM MSM-Occupational Safety	Soc-1
Lost workdays	Workdays missed due to accidents	Number or per cent of workdays missed due to accidents	GRI-labour Practices: Occupational Health and Safety; GM MSM-Occupational Safety	Soc-2
Blood lead level	Levels of lead in the blood of the employees that may be affected by heavy metal processes or operations	Levels of lead in blood (µg/100mL) of the employees that may be affected by heavy metal processes or operations	ISO-14031-Environmental condition indicators: Humans	Soc-3
Health education and wellness programs	Employee participation in on-site health education/wellness programs promoted by an organisation	Number or per cent of employee participation in on-site health education/wellness programs promoted by an organisation	DJSI-Industry Specific Criteria; GM MSM-Personal Health	Soc-4
Sick days	The ratio of sick days to workdays	The ratio of sick days to workdays	GM MSM-Personal Health	Soc-5
Health index of on-site food (cafeteria)	Health index of on-site food	Health index of on-site food	GM MSM-Personal Health	Soc-6
Employee days away	Paid days off	Number of paid days off per facility or employee	GM MSM-Occupational Safety	Soc-7
Employee toxin exposure	Employee exposed to specific toxins and the effects of these exposures-days away due to exposure to toxins	Number of employees or per cent of employees exposed to specific toxins, and the number of days away due to exposure to these toxins	GM MSM-Occupational Safety	Soc-8
Personal protective equipment and safety equipment	Safety gear and safety showers are available to employees and mandated by organisations Procedure	The ratio of safety gear and safety showers to employees that are mandated by an organisations procedure	GM MSM-Occupational Safety	Soc-9
Safety measures adopted	Number of safety measures adopted, safety/fail-safe	Number or per cent of safety measures adopted, safety/fail-safe equipment	GM MSM-Occupational Safety	Soc-10

	equipment installed, and improvements in safety performance from these measures	installed, and estimated reductions in dollar amount from abating accidents from these measures		
Employee health and safety improvement nominations	Safety measures adopted and safety/fail-safe equipment installed due to employee suggestions and improvements in safety performance from these suggestions	Number or per cent of safety measures adopted, safety/fail-safe equipment installed due to employee suggestions, and estimated reductions in dollar amount from abating accidents from these suggestions	GM MSM-Occupational Safety	Soc-11
Injury rate	Injury rate categorised on injury types, such as puncture, laceration, or strain	Injury rate based on injury types, such as puncture, laceration, or strain	GM MSM-Occupational Safety	Soc-12
Employee knowledge empowerment	Empower the employees with the knowledge to make safer choices for themselves and coach their peers to do the same	Number or per cent of employees empowered with the knowledge to make safer choices for themselves and coach their peers to do the same	GM MSM-Occupational Safety	Soc-13
Revitalization efforts in employee suggestion programs	Revitalization of employee suggestions for improvement and specific effort periods for one month or one week a month	Change in the number or per cent of employee suggestions for a given period and number or per cent change from one month or one week a month revitalisation programs	GM MSM-Occupational Safety	Soc-14
The line stops due to safety concerns	The line stops due to safety concerns	Number or per cent of line stops due to safety concerns	GM MSM-Occupational Safety; ISO 14031-Operational performance indicators: Physical facilities and equipment	Soc-15
Representation in joint management-worker health and safety committees	Employees represented in formal joint management-worker health and safety committees that help monitor and advise on occupational health and safety programs	Number or per cent of employees represented in formal joint management-worker health and safety committees that help monitor and advise on occupational health and safety programs	GRI-labour Practices: Occupational Health and Safety; GM MSM-Occupational Safety	Soc-16

Injuries, occupational diseases, lost days, and absenteeism	Injury, occupational diseases, lost days, absenteeism, and work-related fatalities	Breakdown of employee health and safety incidents are broken down by number and per cent according to injuries, occupational diseases, lost days, absenteeism, and fatalities	GM MSM-Occupational Safety	Soc-17
Risk-control programs for diseases	Education, training, counselling, prevention, and risk-control programs in place to assist workforce members, their families, or community members regarding serious diseases	Qualitative	GRI-labour Practices: Occupational Health and Safety	Soc-18
Health and safety agreements	Health and safety topics covered in formal agreements with trade unions	Qualitative	GRI-labour Practices: Occupational Health and Safety	Soc-19
Diffusion of work-related illness	The spread of work-related illness	Increase/decrease in the number of employees affected by work-related illness once the illness is identified and controlled	GM MSM-Occupational Safety	Soc-20
OSHA reported events	OSHA reported events categorised by the process and product is manufactured	Number of reported OSHA events categorised by the process and product is manufactured	DJSI-Labor Practice Indicators; DJSI-Industry Specific Criteria; GM MSM-Occupational Safety	Soc-21
Risk-control programs for injuries	Education, training, counselling, prevention, and employee empowerment to limit the risk of workplace injuries and questionable employee decision	Qualitative	GRI-labour Practices: Occupational Health and Safety	Soc-22
Human rights training for security personnel	Security personnel trained in the organisation's policies or procedures concerning aspects of human rights that are relevant to operations	Number or per cent of security personnel trained in the organisation's policies or procedures concerning aspects of human rights that are relevant to operations	GRI-Human Rights: Security Practices	Soc-23

Average hours of training	Average hours of training per year per employee by employee category	Training per year per employee by employee category	GRI-labour Practices: Training and Education	Soc-24
Skills management programs	Indicate the implementation of your company's formalised skill mapping and developing a process for Executive/Top management, Middle/General management, First line management/Supervisor, Specialists groups, Other employees	Number of programs for skills management and lifelong learning that supports the continued employability of employees and assist them in managing career endings, and number or per cent of employees participating in these programs	GRI-labour Practices: Training and Education; DJSI-Human Capital Development	Soc-25
Employee performance and career development review	Employees receiving regular performance and career development reviews categorised by employee type	Number or per cent of employees receiving regular performance and career development reviews categorised by employee type	GRI-labour Practices: Training and Education; DJSI-Talent Attraction & Retention	Soc-26
Employee Training in Sustainability	Employees trained in basic sustainability concepts and current sustainability initiatives	Percentage of employees trained in basic sustainability concepts and current sustainability initiatives	GM-MSM	Soc-27
Paid days off	Paid days off per facility or employee categorised by employee type	Number of paid days off per facility or employee categorised by employee type	GM MSM-Occupational Safety	Soc-28
Job satisfaction	Satisfaction level of your employees	Satisfaction level of your employee's based on employee surveys and reviews, and number or per cent of employees participating in investigations and assessments	DJSI-Talent Attraction & Retention; DJSI-Labor Practice Indicators	Soc-29
Grievance resolution	Helpline, a whistleblowing policy, independent person/dept. In charge of solving complaints by employees	Qualitative	DJSI-Labor Practice Indicators	Soc-30

	(diversity committee, company ombudsman, etc.), counselling, strict confidentiality ensured, policies and related information widely circulated in appropriate languages			
Life cycle assessment for health and safety impacts	Life cycle stages in which health and safety impacts of products and services are assessed for improvement, and significant products and services categories subject to such procedures	Number of life cycle stages in which health and safety impacts of products and services are assessed for improvement, and number or per cent of significant products and services categories subject to such procedures	GRI-Product Responsibility: Customer Health and Safety	Soc-31
Incidents of non-compliance with voluntary codes	Incidents of non-compliance with regulations and voluntary codes concerning health and safety impacts of products and services during their life cycle, by type of outcomes	Number of incidents of non-compliance with regulations and voluntary codes concerning health and safety impacts of products and services during their life cycle, by type of outcomes	GRI-Product Responsibility: Customer Health and Safety	Soc-32
Product quality assurance and management	Incidents of product recall and customer complaints and resolutions met from these incidents	Number of or dollar amount paid from incidents of product recalls, and customer complaints and number or per cent of resolutions met from these incidents	DJSI-Industry Specific Criteria; Ford PSI-Product Responsibility: Customer Health and Safety	Soc-33
Customer satisfaction assessment	Practices related to customer satisfaction, including results of surveys measuring customer satisfaction	The number and dollar amount of investment practices related to customer satisfaction, including results of surveys measuring customer satisfaction	GRI-Product Responsibility: Product and Service Labeling	Soc-34
Customer complaints	Customer complaints received concerning a product or service for an organisation	Number of customer complaints per year received concerning a product and service	GM-MSM	Soc-35

Product and service information required by procedures	Product and service information required by procedures, and significant products and services subject to such information requirements	Type of product and service information required by procedures, and percentage of significant products and services subject to such information requirements	GRI-Product Responsibility: Product and Service Labeling; DJSI-Industry Specific Criteria	Soc-36
Breaches of customer privacy	Substantiated complaints regarding breaches of customer privacy and losses of customer data	Number of substantiated complaints regarding breaches of customer privacy and losses of customer data	GRI-Product Responsibility: Customer Privacy	Soc-37
Legal actions for anti-competitive behaviour	Legal actions for anti-competitive behaviour, anti-trust, and monopoly practices and their outcomes	Number of legal actions for anti-competitive behaviour, anti-trust, and monopoly practices and dollar amount ensured by their outcomes	GRI-Society Performance: Anti-Competitive Behaviour	Soc-38
The composition of governance bodies	The composition of governance bodies and breakdown of employees per category according to gender, age group, minority group membership, locality, and other indicators	Number or per cent of corporate governance body broken down by category gender, age group, minority group membership, locality, and other indicators	GRI-labour Practices: Diversity and Equal Opportunity; DJSI-Corporate Governance	Soc-39
Salary ratio	The range of ratios of standard entry level wage compared to local minimum wage at significant locations of operation and range of basic wage of men to women by employee category	Ratios of standard entry level wage compared to local minimum wage at significant locations of operation and range of basic wage of men to women by employee category	GRI-Market Presence; GRI-Labor Practices: Diversity and Equal Opportunity; DJSI-Labor Practice Indicators; DJSI-Industry Specific Criteria	Soc-40
Composition of the workforce	The composition of workforce and breakdown of employees per category according to gender, age group, minority group membership, locality, and other indicators	Number or per cent of workforce broken down by category gender, age group, minority group membership, locality, and other indicators	GRI-Market presence; GRI-Labor Practices: Employment	Soc-41

Employee turnover	The rate of employee turnover by age group, gender, and region	Total number and rate of employee turnover by age group, gender, and region	GRI-labour Practices: Employment	Soc-42
Employee benefits	Benefits provided to employees categorised by full-time, part-time, employee level, salary, etc.	Qualitative	GRI-Economic Performance; GRI-Labor Practices: Employment; DJSI-Talent Attraction & Retention	Soc-43
Operation risk assessment for child labour	Operations identified as having significant risk for incidents of child labour, and measures taken to contribute to the elimination of child labour	Number or per cent of operations identified as having significant risk for incidents of child labour and number of resolutions met to eliminate child labour	GRI-Human Rights: Child Labor	Soc-44
Operation risk assessment for force compulsory labour	Operations identified as having significant risk for incidents of forced or compulsory labour, and measures to contribute to the elimination of forced or compulsory labour	Number or per cent of operations identified as having significant risk for incidents of forced or compulsory labour and number of resolutions met to eliminate forced or compulsory labour	GRI-Human Rights: Forced and Compulsory Labor	Soc-45
Employees covered by collective bargaining	Employees covered by collective bargaining agreements	Number or per cent of employees covered by collective bargaining agreements	GRI-Labour Practices: Labor/Management Relations	Soc-46
Operation change notice period	Minimum notice period(s) regarding operational changes, including specified in collective agreements.	Minimum notice period(s) regarding operational changes, including whether it is specified in collective agreements	GRI-Labour Practices: Labor/Management Relations	Soc-47
Operation risk assessment for freedom of association and collective bargaining	Operations identified in which the right to exercise freedom of association and collective bargaining may be at significant risk, and actions	Number or per cent of operations identified in which the right to exercise freedom of association and collective bargaining may be at significant risk, and number of resolutions met to support these rights	GRI-Human Rights: Freedom of Association and Collective Bargaining; DJSI-Labor Practice Indicators	Soc-48

	taken to support these rights			
Human rights screening	Significant investment agreements include human rights clauses or have undergone human rights screening and participation in developed human rights declarations (UN Universal Declaration of Human Rights, ILO Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy, OECD Guidelines for Multinational Enterprises, etc.)	Number or per cent of significant investment agreements that include human rights clauses or that have undergone human rights screening and number of developed human rights declarations (UN Universal Declaration of Human Rights, ILO Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy, OECD Guidelines for Multinational Enterprises, etc.) participated in by an organisation	GRI-Human Rights: Investment and Procurement Practices; DJSI-Labor Practice Indicators	Soc-49
Human rights screening for suppliers and contractors	Significant suppliers and contractors that have undergone screening on human rights and actions are taken	Number or per cent of significant suppliers and contractors that have undergone screening on human rights and actions are taken	GRI-Human Rights: Investment and Procurement Practices	Soc-50
Human rights training	Employee training on policies and procedures concerning aspects of human rights that are relevant to operations	Number or per cent of employees trained on policies and procedures concerning aspects of human rights that are relevant to operations, and the number of hours for this training by an employee	GRI-Human Rights: Investment and Procurement Practices	Soc-51
Incidents of discrimination	Incidents of discrimination and actions are taken	Number of incidents of discrimination and the number of resolutions met for these incidents	GRI-Human Rights: Discrimination	Soc-52
Analyzed business units for corruption	Business units analysed for risks related to corruption and corruption score for those business units	Number of and per cent of business units analysed for risks related to corruption and corruption score for those business units (Standardized scale (z-score); with high scores corresponding to	GRI-Society Performance: Corruption; DJSI-Codes of Conduct/Compliance/Corruption & Bribery; ESI-Social and Institutional Capacity: Environmental Governance	Soc-53

		the effective control of corruption)		
Anti-corruption training	Employees trained in the organisation's anti-corruption policies and procedures are categorised by type	The number and per cent of employees trained in the organisation's anti-corruption policies and procedures categorised by type	GRI-Society Performance: Corruption; DJSI-Codes of Conduct/Compliance/Corruption & Bribery	Soc-54
Response to incidents of corruption	Actions were taken in response to incidents of corruption	Qualitative	GRI-Society Performance: Corruption; DJSI-Codes of Conduct/Compliance/Corruption & Bribery	Soc-55
Paid bribes	Employees have been asked or have complied with government officials' expectations or other outside officials to pay a bribe for their services.	Some per cent of employees have been asked or have complied with government officials or other outside officials' expectations to pay a bribe for their services.	CSD-Governance: Corruption	Soc-56
Incident of conflict of interests	Conflicts of interests or ethical dilemmas for an organisation and its reporting, auditing, and operating agencies	Number of conflicts of interests or ethical dilemmas for an organisation and its reporting, auditing, and operating agencies per period	DJSI-Corporate Governance	Soc-57
General non-compliance fines for products	Significant fines for non-compliance with laws and regulations concerning the provision and use of products and services	The dollar amount of significant fines for non-compliance with laws and regulations concerning the provision and use of products and services	GRI-Society Performance: Compliance; GRI-Product Responsibility: Product and Service Labeling N	Soc-58
Incidents of marketing communications non-compliance	There are non-compliance with regulations and voluntary codes concerning marketing communications, including advertising, promotion, and sponsorship, by type of outcomes.	Total number of incidents of non-compliance with regulations and voluntary codes concerning marketing communications, including advertising, promotion, and sponsorship, by type of outcomes	GRI-Product Responsibility: Marketing Communications	Soc-59
				Soc-60

Incidents of product and service non-compliance	Incidents of non-compliance with regulations and voluntary codes concerning product and service information and labelling, by type of outcomes	Total number of incidents of non-compliance with regulations and voluntary codes concerning product and service information and labelling, by type of outcomes	GRI-Product Responsibility: Marketing Communications	
General non-compliance non-monetary sanctions for product	Significant fines and the total number of non-monetary sanctions for noncompliance with laws and regulations	The dollar amount of significant fines and the total number of non-monetary sanctions for noncompliance with laws and regulations	GRI-Society Performance: Compliance; GRI-Product Responsibility: Product and Service Labeling	Soc-61
Programs for adherence to laws	Programs for adherence to laws, standards, and voluntary codes related to marketing communications, including advertising, promotion, and sponsorship	Number of programs and dollar amount invested for programs for the adherence to laws, standards, and voluntary codes related to marketing communications, including advertising, promotion, and sponsorship	GRI-Product Responsibility: Marketing Communications	Soc-62
Violations of human rights	Incidents of violations involving rights of indigenous people and actions taken	Total number of incidents of violations involving rights of indigenous people and actions taken	GRI-Human Rights: Indigenous Rights	Soc-63
Public service management	Nature, scope, and effectiveness of any programs and practices that assess and manage the impacts of operations on communities, including entering, operating, and exiting	Qualitative	GRI-Society Performance: Public Policy	Soc-64
Participation in public policy development	Public policy positions and participation in public policy development and lobbying	Qualitative	GRI-Society Performance: Public Policy	Soc-65

Political contributions	Financial and in-kind contributions to political parties, politicians, and related institutions by country	The total dollar amount of financial and in-kind contributions to political parties, politicians, and related institutions by country	GRI-Society Performance: Public Policy	Soc-66
Responsible Care Program participation	Participation in the Responsible Care Program of the Chemical Manufacturer's Association	Level of participation in the Responsible Care Program of the Chemical Manufacturer's Association, Score from 0 (low) to 4 (high) levels of participation	ESI-Social and Institutional Capacity: Private Sector Responsiveness	Soc-67
Sustainability report publishing	Public reporting of common sustainability assessments and level of reporting of those assessments (i.e. GRI, WSPI, etc.)	Number of public sustainability assessments and reports published and per cent of completion of those sustainability assessments	DJSI-Social Reporting; ESI-Social and Institutional Capacity: Private Sector Responsiveness; ESI-Social and Institutional Capacity: Private Sector Responsiveness	Soc-68
Population density	The population density in the surrounding area of an organisation or facility	Number of people per surrounding area of an organisation or facility	ISO 14031-Environmental condition indicators: Humans	Soc-69
Population growth	The growth of the surrounding community of an organisation or facility	Change in the number of people per period of the surrounding community of an organisation or facility	ISO 14031-Environmental indicators: Humans; CSD-Demographic: Population	Soc-70

Indicators name	Explanation	Unit	References	ID a
Technology Purchases	Technologies or products purchased for manufacturing	Number of technologies or products imported from outside the country of residence for an organisation	NISTEP	Tech-1
Technology exports	Technologies or products sold by a manufacturing organisation	Number of technologies or products exported outside the country of residence for an organisation	ESI-Social Institutional Capacity: Environmental Governance; NISTEP	Tech-2
Product output	Throughput for a specific product	Number of a specific product produced in a period	NISTEP	Tech-3
High tech product output	Licenses sold for improved processes (for technology licensing organisation)	Number of licenses sold for improved processes (for technology licensing organisation)	NISTEP; ESI-Social and Institutional Capacity: Private Sector Responsiveness; ISO 14031-Operational performance indicators: Services provided by the organisation	Tech-4
Bachelors of Science	Number of persons with a Bachelor of Science degree	Number of persons with a Bachelor of Science degree	NISTEP	Tech-5
Bachelors of Engineering	Number of persons with a Bachelor of Engineering degree	Number of persons with a Bachelor of Engineering degree	NISTEP	Tech-6
R&D scientists/engineers	Number of R&D scientists/engineers	Number of R&D scientists/engineers	NISTEP	Tech-7
Scientific papers	Scientific papers published by an organisation	Number of scientific papers published by an organisation	NISTEP	Tech-8
Scientific paper citations	Citations for scientific papers produced by an organisation	Number of citations for scientific papers produced by an organisation	NISTEP	Tech-9
Domestic patents	Domestic patents received or applied for by an organisation or for a product	Number of domestic patents received or applied for by an organisation or for a product	NISTEP	Tech-10
External patents			NISTEP	Tech-11

	External patents received or applied for by an organisation or for a product	Number of external patents received or applied for by an organisation or for a product		
Patent Citations	Citations for given patents from an organisation or product	Number of citations for given patents from an organisation or product	NISTEP	Tech-12

Indicators name	Explanation	Unit	References	ID
Achieved objectives	Objectives set by an organisation for its operations and processes and the achievement of those objectives	The degree of completion of set objectives by an organisation for its operations and processes, including set reductions, increases, or improvements	W SPI-Energy and Climate: Reducing Energy Costs and Greenhouse Gas Emissions; W SPI-Material Efficiency: Reducing Waste and Enhancing Quality; ISO 14031-Management performance indicators: Implementation and programs	Per-1
Units achieving environmental objectives	Organizational units, facilities, processes achieving environmental objectives and targets	Number or per cent of organisational units, facilities, or processes achieving environmental objectives and targets	DJSI-Environmental Reporting; ISO 14031-Management performance indicators: Implementation and programs	Per-2
Regulation compliance	Compliance of an organisation's operations or processes with standard regulations	The degree of compliance of an organisation's operations or processes with standard regulations	W SPI-People and Community: Ensuring Responsible and Ethical Production; ISO 14031-Management performance indicators: Conformance	Per-3
Service provider conformance	Compliance of an organisation's service providers or contractors with standard regulations and the organisation's contracts	The degree of compliance of an organisation's service providers or contractors with standard regulations and the organisation's contract	ISO 14031-Management performance indicators: Conformance	Per-4
Environment incident response time	Time to respond to or correct environmental incidents	Time to respond to or correct environmental incidents	ISO 14031-Management performance indicators: Conformance	Per-5
Corrective measures	Identified corrective actions from an organisation's auditing process that have been resolved or that are unresolved	Number of identified corrective actions from an organisation's auditing process that have been resolved or that are unresolved	ISO 14031-Management performance indicators: Conformance	Per-6

Environmental fines and penalties	Attributable environmental fines for an organisation's performance concerning environmental laws and regulations	The dollar amount of environmental fines attributed to an organisation's performance in regards to environmental laws and regulations	GRI-Compliance; ISO 14031-Management performance indicators: Conformance	Per-7
Frequency of audits	The frequency of audits categorised by external and internal	Number of audits performed per period categorised by external and internal audits	ISO 14031-Management performance indicators: Conformance	Per-8
Audits completed versus planned	Audits completed for an organisation compared to the number of audits planned for the organisation categorised by external and internal auditing	Number of audits completed versus planned categorised by external and internal auditing	ISO 14031-Management performance indicators: Conformance	Per-9
Audit findings	An organisation's auditing program is used to find areas of improvement and focus categorised by external and internal auditing	Number of audits performed per period and the number of findings of the audits categorised by external and internal auditing	ISO 14031-Management performance indicators: Conformance	Per-10
The frequency of review of operating procedures	The frequency of review of operating procedures for an organisation or process	Number of investigations and reviews for operating procedures for an organisation or process	ISO 14031-Management performance indicators: Conformance	Per-11
Emergency drills conducted	Number of emergency drills conducted	Number of emergency drills conducted	ISO 14031-Management performance indicators: Conformance	Per-12
Emergency preparedness	Percentage of emergency preparedness and response drills demonstrating planned readiness during emergency drills and emergency events	Percentage of emergency preparedness and response drills demonstrating planned readiness during emergency drills and emergency events	ISO 14031-Management performance indicators: Conformance	Per-13

Breaches of conduct reporting	Public reporting of bribes or breaches of codes of conduct for an organisation	Number of reports on bribes or breaches of conduct for an organisation	DJSI-Codes of Conduct/Compliance/Corruption & Bribery	Per-14
Implementation of specified environmental codes & practices	Implementation of specified codes of management or operating practices for an organisation or process. Concerns: environmental codes and regulations, third-party certifications, supply chain management, etc.	The degree of implementation of specified codes of management or operating practices for an organisation or process	DJSI-Environmental Performance (Eco-Efficiency); DJSI-Environmental Reporting; W SPI-Natural Resources: Producing High Quality, Responsibly Sourced Raw Materials; ISO 14031-Management performance indicators: Implementation and programs; EEA CSI-Terrestrial	Per-15
Pollution prevention initiatives	Pollution prevention initiatives for organisations, processes, and products implemented and results of this initiative	Some pollution prevention initiatives for organisations, processes, and products implemented and results from these initiatives, including GHG reductions, ozone depletion abatement, etc.	GRI-Emissions, effluents, and waste; GRI-Products and Services; DJSI-Industry Specific Criteria; ISO 14031-Management performance indicators: Implementation and programs; ISO 14031-Operational performance indicators: Physical facilities and equipment; ISO 14031-Operational performance indicators: Supply and delivery; ISO 14031-Operational performance indicators: Products; OECD-Pollution Issues: Air quality; EEA CSI-Climate change; EEA CSI-Transport	Per-16
Environmental responsibilities for management	Levels of management with specific environmental responsibilities	Number or per cent of levels of management with specific environmental responsibilities	DJSI-Corporate Governance; DJSI-Industry Specific Criteria; ISO 14031-Management performance indicators: Implementation and programs	Per-17
Employee environmental requirements	Employees that have environmental requirements in their job descriptions	Number or per cent of employees that have environmental requirements in their job descriptions	ISO 14031-Management performance indicators: Implementation and programs	Per-18
Employee participation in environmental activities	Employees participating in environmental programs (e.g. suggestion, recycle, clean-up initiatives, carpooling, eco-	Number or per cent of employees participating in environmental programs (e.g. suggestion, recycle, clean-up	GM MSM-Environmental Impacts; ISO 14031-Management performance indicators: Implementation and programs	Per-19

	friendly transportation, etc.)	initiatives, carpooling, eco-friendly transportation, etc.)		
Employee recognition in environmental programs	Employees who have obtained reward and recognition in participation in an organisation's or related environmental programs	Number or per cent of employees who have obtained reward and recognition in participation in an organisation's or related environmental programs compared to the total number of employees who participated in the program	GM MSM-Energy Consumption; ISO 14031-Management performance indicators: Implementation and programs	Per-20
Employee training ratio	Employees trained versus the number that needs training	Number or per cent of employees trained versus the number that needs training	ISO 14031-Management performance indicators: Implementation and programs	Per-21
Trained contracted individuals	Contracted individuals trained and certified for specific operations involving safety or environmental issues	Number or per cent of contracted individuals trained and certified for specific operations involving safety or environmental issues	ISO 14031-Management performance indicators: Implementation and programs	Per-22
Training effectiveness	Levels of knowledge obtained by training participants	Qualitative	ISO 14031-Management performance indicators: Implementation and programs NIST-SMIR	Per-23
Employee environmental suggestions	Suggestions made by employees regarding environmental concerns and improvements	Number of suggestions made by employees regarding environmental concerns and improvements	ISO 14031	Per-24
Employee environmental knowledge	Results of employee surveys on their knowledge of the organisation’s	Qualitative	ISO 14031-Management performance indicators: Implementation and programs	Per-25

	environmental issues			
Suppliers' environmental awareness	Suppliers and contractors queried about environmental issues by an organization or external entity	Number or per cent of suppliers and contractors queried about environmental issues by an organisation or external entity	DJSI-Industry Specific Criteria; Ford PSI-Environmental Health: Air Pollution (effects on humans); W SPI-Natural Resources: Producing High Quality, Responsibly Sourced Raw Materials; W SPI-People and Community: Ensuring Responsible and Ethical Production; ISO 14031-Management performance indicators: Implementation and programs	Per-26
Environmentally certified service providers	Contracted service providers with an implemented or certified environmental management system	Number or per cent of contracted service providers with an implemented or certified environmental management system	ISO 14031-Management performance indicators: Implementation and programs	Per-27
Product stewardship	Products with explicit “product stewardship” plans	Number or per cent of products with explicit “product stewardship” plans	ISO 14031-Management performance indicators: Implementation and programs; DJSI-Industry Specific Criteria	Per-28
Design for environmental products	Products and equipment used that is designed for disassembly, recycling or reuse	Number or per cent of products or equipment used designed for disassembly, recycling, or reuse categorised by type	ISO 14031-Management performance indicators: Implementation and programs; ISO 14031-Operational performance indicators: Physical facilities and equipment; ISO 14031-Operational performance indicators: Products	Per-29
Product disposal instructions	Products with instructions regarding the environmentally safe use and disposal	Number or per cent of products with instructions regarding the environmentally safe use and disposal	ISO 14031-Management performance indicators: Implementation and programs	Per-30