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Abstract

Purpose: The use of quality management (QM) to achieve the United Nations Sustainable Development Goals (UNSDGs) is a topic of growing interest in academia and industry. The IAQ (International Academy for Quality) established Quality Sustainability Award in 2020, a testament to this growing interest. This study aims to investigate how QM philosophies, methodologies, and tools can be used to achieve sustainable development in organizations.

Design/methodology/approach: Five large manufacturing organizations – three from India and two from China – who reported their achievements about using QM in achieving Sustainable Development Goals (SDGs) were studied using multiple sources of data collection. A detailed within-case and cross-case analysis were conducted to unearth this linkage's practical and theoretical aspects.

Findings: The study finds that QM methodologies effectively met the five organizations' UNSDGs. These organizations successfully used OPEX (Operational Excellence) methodologies such as Lean, Kaizen and Six Sigma to meet UNSDGs 7, 11, 12 and 13. Moreover, UNSG 12 (Responsible Consumption and Production) is the most targeted goal across the case studies. A cross-case analysis revealed that the most frequently used quality tools were Design of Experiments (DoE), Measurement Systems Analysis (MSA), C&E analysis, and Inferential statistics, among other essential tools.

Research limitations: The study's sample size was limited to large-scale manufacturing organizations in the two most populous countries in the world. This may limit the study's generalizability to other countries, continents, or micro, small and medium-sized enterprises (SMEs). Additionally, the study's conclusions would be strengthened if tested as hypotheses in a follow-up survey.

Practical implications: This practical paper provides case studies on how to use QM to impact SDGs. It offers both descriptive and prescriptive solutions for practitioners. The study highlights the importance of using essential QM tools in a structured and systematic manner, with effective teams, to meet the SDGs of organizations.

Social implications: The study shows how QM can be used to impact UNSDGs, and this is very important because the UNSDGs are a set of global objectives that aim to address a wide range of social and environmental issues. This study could motivate organizations to achieve

the UNSDGs using essential QM tools and make the world a better place for the present and future generations.

Originality: This case study is the first to investigate at a micro level how QM can impact UNSDGs using live examples. It uses data from the IAQ to demonstrate how QM can be integrated into UNSDGs to ensure sustainable manufacturing.

Keywords: Quality Management; United Nations Sustainable Development Goals; International Academy of Quality; Operational Excellence

1. Introduction

Sustainable development has emerged as a paramount consideration in most organizational strategies. This shift is primarily motivated by the growing global population and the escalating reliance of industrial production activities on non-renewable resources (Deng, 2015). Indeed, the IAQ (International Academy for Quality) Quality Sustainability Award was established in 2020 to recognize how QM philosophies, methodologies, and tools have been used to achieve more sustainable development (IAQ, 2023). However, QM as a means for sustainability achievements in organizations is not new. It was introduced in the mid-1990 and is expected to be more critical than ever in the Quality 2030 research agenda (Fundin *et al.*, 2020). Scholars' and practitioners' interest in sustainability is increasing with urgent challenges. At the same time, existing measurement frameworks of Corporate Social Responsibility (CSR) are limited (Ramanathan and Isaksson, 2022). Hence, this international award is given to projects that have successfully shown how quality could drive sustainable development in organizations. Successfully implemented projects promote fact-based, results-focused, and improvement-driven sustainability work. In this context, sustainability is created as resources are transformed into customer and stakeholder value and QM in organizational processes. Effectiveness and efficiency could be improved using a QM philosophy, methodology and tools professionally. A higher value could be delivered to customers and stakeholders with less use of resources (Noronha *et al.*, 2022; Ramadan *et al.*, 2023).

Sustainability is a complex concept. This article uses sustainable development as a basic concept that strives to balance organizational ecological, social, and economic development, in line with Deleryd and Fundin (2020). One of the most commonly used definitions of sustainable development is the United Nations (UN) 'Brundtland definition' that states "*meeting the needs of the present without compromising the ability of future generations to meet their own needs*" (Secretary-General and Development, 1987). Through Agenda 2030, the UN has

quantified the sustainability development focus through the 17 global development goals covering several vital areas for humanity (United Nations, 2022). The debate on sustainability is most often discussed from a *macro-perspective* focusing on consequences and effects on planet Earth caused by humans. To tackle the challenge of achieving sustainable development, the macro-perspective could provide a target image of a sustainable future. The challenges must also be managed from a *micro-perspective*, i.e., within the processes of organizations, where resources are transformed into customer value. Total quality management (TQM) programs could positively affect corporate sustainability (Makhlouf *et al.*, 2023). Also, QM philosophies, methods and tools are considered to be necessary means towards value creation and sustainable development from the micro-perspective in organizations (Akanmu, Hassan, Ibrahim Alshuaibi, *et al.*, 2023; Xu *et al.*, 2023), even if there are several challenges and barriers (Kumar *et al.*, 2020). Still, the objective of QM is to meet and preferably exceed customer needs to improve efficiency and effectiveness continuously. Integrating QM knowledge into the efforts to achieve sustainable development seems to be a great potential to contribute to ecologically, socially, and economically sustainable goals.

Hence, this article focuses on QM to gain sustainability development through micro-level competence in private (Antony *et al.*, 2023) and public organizations (Bhat, Gijo, *et al.*, 2023). S*ustainability micro competence* in the context of this study is about improving organizations, developing processes, solving problems, and creating innovations that are critical in achieving sustainable development. Experts and researchers within QM have many years of experience developing the QM knowledge domain. Today the philosophies, methodologies and tools are far more critical than ever to drive sustainable development in organizations through concepts such as Business Excellence models, TQM, Six Sigma, Lean, Kaikaku and Kaizen. Therefore, the paper addresses the main research question, "*How could QM philosophies, methodologies and tools be critical means to achieving sustainable development in organizations?"*

First, we conduct a literature review on QM and its relation to sustainable development together with an analysis and review of five IAQ sustainability award cases. The novelty of this study is to develop new knowledge of the potential contributions of QM in addressing the sustainability challenge. The scope of our study emphasizes sustainability micro-level perspective in organizations considering five international cases selected based on their uniqueness and relevance for sustainability development in organizations. The remainder of this article is organized as follows: Section 2 highlights the key works from the literature

review, and Section 3 outlines the methodology utilized. We subsequently describe the case studies in Section 4 and proceed with the discussion in Section 5. Conclusions, limitations and key future research are presented in Section 6.

2. Literature Review

Research on the relationship between quality and sustainability has increased dramatically last 25 years (Carnerud *et al.*, 2020). Previous studies have shown many variations on how quality could be applied together with sustainability perspectives. In a literature review on how QM approaches have been applied to promote sustainable development, (Siva *et al.*, 2016) identified that most research has been conducted within "supporting sustainability through the integration of management systems" and "quality management as support to the implementation of environmental management systems and the management of sustainability". In the current article, we extensively reviewed articles published in international journals known as prominent for the discourse of QM and how research on QM is related to sustainability. The review shows three distinct areas that could explain the relationship between quality and sustainability: 1) Quality as a driver of sustainable development, 2) Quality as a mediator for sustainable development, and 3) Quality as a contributor to sustainable development.

2.1 Quality as a Driver of sustainable development

Quality as a driver of sustainable development could be described from various perspectives. The first aspect is referred to measurement frameworks based on quality, as described by Ramanathan and Isaksson (2022). Although measurement frameworks of CSR may have limitations in terms of aligning a company's environmental footprint to mitigate climate change, the researchers suggest a quality framework aligns with sustainability reporting (Ramanathan and Isaksson, 2022). In line with these ideas, Hudnurkar *et al.* (2022) claim that QM can provide a holistic means for stakeholders to achieve corporate sustainability (CS). The researchers explain that innovation capability is a necessary means of achieving CS.

Another approach to how quality could be a driver of sustainable development is presented by Vandenbrande (2021), showing how a new quality-based definition could support achieving economic and social sustainability. Studying the longitudinal trends of two successive Delphi studies, Deleryd and Fundin (2020) propose a generic model for sustainable development aiming to balance economic, social and environmental sustainability. Thus, quality principles

could support sustainable development in organizations in many ways. Akanmu, Hassan, Mohamad, *et al.* (2023) show that integrating QM principles and activities such as quality assurance, continuous process improvement, service design, benchmarking, and information and analysis drives organizational sustainability. This is also verified by a study by de Nadae *et al.* (2021), revealing that sustainability was not an influential factor for implementing integrated management systems. However, it was observed that the implementation of such systems was a powerful driver of sustainability performance. While QM often brings to the fore through management systems, one can argue that quality, in this case, would be a driver of sustainable development. Integrated management systems seem to be a successful way of doing this.

However, quality as a driver for sustainable development is not a source of strength per se. According to Kumar et al. (2020), organizations must address the critical barriers to improve their organizational performance. While Ronalter and Bernardo (2023) studied how integrated management systems could drive sustainable development and corporate sustainability, they also addressed critical knowledge gaps. It is not easy to achieve sustainable development without clear definitions and performance indicators (Isaksson *et al.*, 2022). The authors describe how QM could be a supportive element in this vital work.

While quality could be a driver for sustainable development, the definition of quality and the implications for QM shows a broad spectrum of how to achieve this in practice. Khan and Naeem (2018) find that strategic quality management influences innovation capabilities and sustainable development. Their study describes QM in terms of continuous improvement, strategic quality management, human resources management, supplier relationship and corporate quality culture. Sureshchandar (2022) explain how Quality 4.0 contributes to sustainability through 12 QM dimensions: quality culture, quality systems, analytical thinking, customer focus, compliance, competence and data-driven decision-making. While sustainability requires a perspective on quality that is inclusive of a broader range of stakeholders, Martin *et al.* (2020) explore four different perspectives on QM: Quality-as-customer-value, Quality-as-agreed-delivery, Quality-as-ecosystems-integration, and Quality-as-society-values.

Finally, some research studies have explored quality tools and techniques to drive organizational sustainability. For example, Cronemyr and Huge-Brodin (2022) propose a tool

based on Quality Function Deployment (QFD) named Green Karma to manage environmental sustainability. Other studies explore combinations of quality practices, such as the study by Gaikwad and Sunnapwar (2021) explaining how manufacturing firms could improve social, economic and environmental sustainability through integrated Lean and Green Six Sigma practices into their supply chain. Lastly, Savastano *et al.* (2022) find evidence from a digital business maturity model study that quality-based principles such as continuous improvement approaches, effective leadership, people-centred management, facts-driven management and constant customer focus positively affect sustainable development in organizations.

2.2 Quality as a Mediator for sustainable development

Furthermore, several studies have indicated the paramount role of quality as a mediator for sustainable development. In other words, QM is critical to achieving sustainability but not always the main driver. For example, Akanmu *et al.* (2023) explore the mediating roles of organizational excellence as a critical influence on the relationship between QM practices and sustainability. In line with the study by Akanmu *et al.* (2023), Xu *et al.* (2023) describe how to achieve business excellence through sustainable supply chain management (SSCM) practices. While quality is integrated into achieving business excellence, this study confirms that quality could have an intermediate role in achieving sustainable development.

Similarly, AlQershi *et al.* (2023) investigate the mediating effect on QM while so-called green creativity does have an effect on QM that does influence business sustainability. Likewise, Tasleem *et al.* (2019) investigate QM's role as a mediating factor influencing sustainable development and corporate sustainability performance. Comparably, Fok *et al.* (2023) assert that both organizational culture and QM practices have a substantial and indirect impact on the relationship between green practices and sustainability performance.

Furthermore, another study by Hassis *et al.* (2023) confirms the indirect impact of QM on CS through CSR as a mediator. Also, Lande *et al.* (2022) study the significant effect of critical success factors of QM to facilitate sustainable development in organizations. This reasoning is also supported by Carvalho *et al.* (2019), which propose a new theory that Operational Excellence (OPEX), including organizational culture and agility, could facilitate sustainable development in organizations. Hence, their theory on QM regarding OPEX could act as a mediator for sustainability.

2.3 Quality as a Contributor to sustainable development

Finally, our literature review finds a third category of quality and its relation to sustainability; *quality as a contributor to sustainable development*. These research studies describe quality as a piece of the puzzle to define sustainable development. For example, research by Makhlouf *et al.* (2023) shows the importance of the combination of QM, Green Innovation (GI) and Green Supply Chain (GSCM) practices to achieve CS. Also, according to (Maletič *et al.*, 2016), there is a positive correlation between sustainability-oriented innovation practices and overall organizational performance, such as economic, quality, Innovation, environmental and social performance.

However, the interconnection of the two knowledge domains of quality and sustainability is not new. According to an extensive literature review, Carnerud *et al.* (2020) describe how sustainability was introduced into the scholarly scene of QM in 1996. The interest in combining the two concepts has since then considerably increased. A recent study by Singh *et al.* (2023) introduces the concept of Data-Driven Sustainability QM practices such as data analytics, QM, and sustainable practices. These practices are critical means in a piece of the puzzle to achieving sustainable development in organizations. Similarly, Esposito *et al.* (2021) explain the positive influence of company size on CSR and quality certification disclosure. Quality thus becomes an integrated cornerstone and contributes to the definition of overall CS in organizations.

New research studies on QM and its contribution to sustainable development also drive the development of new perspectives on sustainability. Hallencreutz *et al.* (2020) highlight the significance of incorporating new QM perspectives with a broader stakeholder perspective as a critical contributor to the concept of sustainable development. Moreover, through a case study of the company Patagonia, (Dezi *et al.*, 2022) demonstrated that the common drivers of QM, Circular Economy (CE) and Social Enterprises (SE) also explain the Triple Bottom Line (i.e., economic, social, and environmental sustainability). In line with this, Huma *et al.* (2023) stressed that a triple-bottom-line improvement could be achieved by integrating supply chain quality with green practices. Finally, Bagur-Femenías *et al.* (2015) claimed that embracing sustainability as a strategic commitment could be a valuable approach to improve the company's financial performance. Improving competitiveness and integrating environmental policies are mediators between quality and finance. Accordingly, quality is a critical contributor to a complete system to achieve sustainable development in the organization.

Existing literature highlights the influence of QM on attaining sustainable development. Still, no prior studies have delved explicitly into the role of QM on sustainability from a micro-level perspective. Therefore, the current research fills this gap by examining sustainability-linked OPEX and providing practical evidence through case studies derived from real-life experiences within the industry sectors.

3. Methodology

To obtain relevant conclusions, we performed an exploratory study incorporating multiple case study analyses (Bhat *et al.*, 2023). Case study methods are often used to study complex processes, allowing for a deeper understanding of the phenomenon under investigation (Yin, 2005). QM and its impact on SDGs is a complex process and needs a more profound understanding to study the various variables. A multiple case study methodology is adopted in light of this article's objective. This approach was chosen because it allows for data collection from multiple sources, which can help to provide a more complete and nuanced understanding of the phenomenon (Eisenhardt, 1989; Yin, 2011). The multiple-case approach was developed by Eisenhardt (1989), who argued that it is a more effective way to generate theory than a single-case study. Eisenhardt (1989) also argued that using secondary data and observations in each case contributes to developing valuable insights and establishing the basis for greater transferability of the findings across other contexts. Theoretical sampling was used to select the case studies. The authors used the IAQ database to identify organizations that have used QM methodologies to attain United Nations Sustainable Development Goals (UNSDGs). More precisely, case studies which won IAQ Sustainability awards are considered. Most of the other articles have used a sample size of around 5 in multiple case study researches (Ano and Bent, 2022; Bhat, Antony, *et al.*, 2023; Bhat *et al.*, 2020; Lwakatare *et al.*, 2019). Thus, a sample size of five case studies was chosen for detailed analyses from India and China. These countries have the highest total population, leading to cascading effects on the earth and society.

Data were collected on each organization in a semi-structured manner. The details sought from each organization were the description of the organization, details of the project description which has impacted sustainable development goals, the QM tools and methodology used, how successful the project and its impact on sustainable development goals. Each case study approach was used to investigate the processes by organizations through QM methodologies to achieve sustainable development goals. Within-case analysis was conducted to gain a

profound comprehension of the processes experienced by each organization (Hancock *et al.*, 2021). A timeline was developed for each company to track their progress. A cross-case analysis was then conducted to compare the organizations and identify similarities and differences in their approaches (Stake, 1995). This analysis led to the development of several theoretical categories and sub-categories.

4. Results

The results and analysis section are divided into two parts. First, we conduct a within-case analysis on all five case studies. Subsequently, cross-case analysis is carried out to bring out higher order understanding of QM and SDGs.

4.1 Within case analysis of Company A:

Brief Description of the Company:

Company A is a pioneer in the Indian Tyre industry. Established in the latter half of the 1950s, the firm has manufacturing facilities in India, Sri Lanka, and Bangladesh, with a significant domestic and international footprint. The firm manufactures Tyres for vehicles such as motorcycles, bicycles, automobiles, trucks, and tractors. The firm has garnered several honours and recognition for its pioneering work in the Tyre industry and the quality and Innovation of its products. The company has demonstrated a resolute commitment to sustainability and proactively implemented various initiatives to minimize its carbon impact and promote environmental sustainability.

Problem Statement and its Alignment with UNSDGs:

Almost all raw materials required to manufacture tyres, except for natural rubber, silica, and other earthy components, are directly or indirectly derived from petroleum. Also, the Tyre production process is very energy intensive. Tyres are a highly impactful product regarding sustainability since they directly affect fuel consumption throughout the consumer use phase of a vehicle. Eventually, it is determined that the usage phase contributes to more than 98% of the carbon footprint. Thus, it is identified as the focused area to improve sustainability. Since Tyre rolling resistance coefficient (RRC) measures energy consumed by the Tyre, it is identified as the project's technical Key Performance Indicator (KPI). By decreasing RRC, fuel efficiency may be enhanced and the carbon footprint minimized. Thus, the case study aims to reduce the carbon footprint by minimizing the RRC of Passenger Car Radial (PCR) tyres yearly

and achieve a 35% reduction in a typical tyre size within six years. The Critical-to-Quality (CTQ) was PCR Tyre, and the objective was to reduce its RRC from 12 to 7.8.

Quality Tools, Techniques and Methodologies Utilized:

Initially, the company followed the TQM framework and policy deployment procedures to execute the project. TQM is integrated into technical tools such as Finite Element Analysis (FEA), Simulation and Rapid Prototyping methodology. Further collaboration with external experts and vendors was initiated for the intellectual interventions. The company established yearly technical targets through policy and procedures. The goal-mean approach is used for deploying the goal throughout the R&D department. Statistical tools like Analysis of Variance (ANOVA), Hypothesis testing, Design of Experiments (DOE), and Analytical Hierarchy Process (AHP) are extensively used for validating and optimizing the factors. Kaizens and Quick-win opportunities were implemented continuously.

Benefits achieved from the Sustainable Performance lens:

The product achieved 7.5 RRC values against the targeted 7.8 RRC. Also, a 37.5% reduction in typical tyre size is achieved against the 35% target. The business introduced the PCR tyres a year earlier than planned. In the following fiscal year, the strategy for continuous improvement enabled the development and validation of a tyre with an RRC of 5.5, a better global standard. As a result of the project, the PCR product's carbon footprint was decreased by 37%. In addition, the project outcomes contributed marginally to the increased use of silica filler (earthen) rather than carbon black filler (Petroleum based). Overall, the project addressed the three UNSDGs. Reduced air pollution due to low emissions induced by decreased gasoline usage directly impacts UNSDG 11 (Make Cities and human settlements inclusive, safe, resilient, and sustainable). This improvement in the utilization of petroleum resources for vehicle mobility and the reduction in the use of raw tyre materials directly affects the achievement of UNSDG 12 (Responsible Consumption and Production). Also, reducing carbon footprint and emissions affects UNSDG 13 (Take immediate action to prevent climate change and its effects).

Implications for Managers:

The organization used a TQM-based QM system for all development initiatives, including the current project. Thus, consistency in OPEX strategy may help to build proficiency in the company and knowledge gained over the period can be tapped during the improvement

initiatives. The cross-functional teams are critical for the project's success, and each step needs to be reviewed by functional heads periodically to reduce project backlash. DOE is one of the better tools for determining the optimal parameters and their levels through the optimal utilization of available resources. Inferential statistics must be used to confirm the validation results during prototyping and bulk validation. Kaizens and Quick-win opportunities, if implemented as part of the Daily work management review, mainly in processes, will immensely contribute to the project's timely completion. Technical know-how and joint developments with suppliers and universities may help generate alternatives in Material, Design and Construction technologies. Failure mode effect analysis (FMEA) for Design and Process will be a more prominent risk mitigation tool.

Key Lessons Learned:

During the project, it is determined that innovative technology development significantly impacts sustainability and affects the carbon footprint throughout the Tyre life cycle, from raw material preparation to manufacturing to usage to end-of-life disposal. Moreover, DOE and computer-aided simulation drastically reduced the design cycle time. Also, integrating DOE with simulation considerably improves the product's robustness. Besides, Taguchi Robust DOE techniques help to study the impact of process noise and help in Design for Manufacturability (DFM).

4.2 Within Case Analysis of Company B:

Brief Description of the Company:

The company is an Indian multinational automotive manufacturing corporation headquartered in Mumbai. It was established in the 1940s and is one of India's most extensive vehicle manufacturers by production. Later, the company's vision led to establishing a premier quality institute to create a quality culture and drive organization-wide excellence. This helped the company to establish its quality philosophy and roadmap for execution. As a responsible organization, it is now venturing into attaining UNSDGs by linking its quality management system.

Problem Statement and its Alignment with UNSDGs:

The company plans to double its energy productivity and transition to 100% renewable energy by 2030. Thus, as a first step, one of its plants was considered for reducing carbon emissions by 18% by FY20 through leveraging OPEX methodology, Innovation and technology. It is

estimated that lighting contributes 34% to the total energy consumption. Further, it was observed that the root cause was process limitations due to traditional technology used in motors & lighting and no infrastructure for renewable energy generation. Thus, the management decided that adopting energy-efficient products & renewable energy sources was the way forward. This vision led to establishing a project to use energy-efficient products to improve energy productivity by improving the performance of electrical and mechanical equipment (motors, pumps, fans, ACs and Lighting). Also, it has set a target to enhance the renewable energy share through solar & windmill.

Quality Tools, Techniques and Methodologies Utilized:

The organization effectively used the DMAIC methodology during the project. Moreover, DOE was used to determine the optimal process parameters for improving energy efficiency. Also, root cause analysis is used to validate the potential causes. It has adopted internal quality principal, namely the Rise philosophy (Accepting No Limits, Alternative Thinking and Driving Positive Change), Quality System Manufacturing Model (First Time Right and Every Time Right) and Sustainability Framework (Rejuvenating the Environment & Enabling Stakeholders to Rise).

Benefits achieved from the Sustainable Performance lens:

The approach and methodologies followed across the projects are replicated in similar settings across the company and extended to supplier ecosystems. The learnings gained from these projects are linked to the knowledge management of the system. Eventually, the project ensured a CO_2 savings of 7583 tons, electricity savings of 10.7 million kWh and cost savings of Rs 90 million. This led to a reduction in carbon emissions by 7583 tons. In this way, the project attained UNSDG 7 (Affordable and Clean Energy) and UNSDG 13 (Climate Action).

Implications for Managers:

It is essential to have internal QM philosophy, models and roadmaps to integrate quality into sustainability goals as defined by the UN. It is observed from the case study that building trust, teamwork, and collaboration is essential to link quality projects to sustainability goals. The case study reported that traditional technologies and a lack of renewable energy infrastructure are the major bottlenecks to energy efficiency in the automobile industry. Thus, it is the responsibility of organizations to establish an ecosystem to integrate quality and sustainability. Moreover, working knowledge of analytical and statistical tools such as DOE, PFMEA,

Correlation, Regression, DMAIC, Six Sigma, and Root cause analyses are essential for sustainability-related projects. Also, the results of successful projects can be deployed company-wide through the employees who are a part of the project execution team by empowering them to act as a coach to other teams.

Key Lessons Learned:

The project was successful since the organization established a "Less is more" mindset amongst teams, keeping the need for creating an impact intact. Further, it is observed that ensuring optimum resource utilization by continuously striving for perfection in planning, allocating and on-time delivery is critical for the project. Besides, company culture must cultivate the habit of 'Make' instead of 'Buy' by leveraging available resources & intellectual diversity. Also, understanding the essential aspects of Innovation, such as problem definition, idea generation, idea selection, iterative prototype testing, and implementation, are critical. In addition, it is necessary to consistently explore & evaluate emerging opportunities by challenging existing conventional thinking. Significantly, in-depth process knowledge can transform potential into performance.

4.3 Within Case Analysis of Company C

Brief Description of the Company:

This company is one of India's leading automobile giants, acclaimed for its global leadership in the commercial vehicle industry. It is considered the second-largest manufacturer of commercial vehicles in India, the fourth-largest manufacturer of buses worldwide, and the nineteenth-largest manufacturer of trucks. The company has a strong presence spanning over 50 countries, offering a diverse range of products, including trucks, buses, and defence vehicles. The company is also committed to sustainability and has developed products that meet the latest emission standards.

Problem Statement and its Alignment with UNSDGs:

In commercial vehicle manufacturing, painting is one of the crucial processes which generates sludge (hazardous waste). To comply with the waste management rules prevalent in the country, the company decided to innovate to reduce waste generation continually. As per state regulation, the permitted limit for paint sludge generation is 300 MT/annum, while only 24 MT per year for phosphate sludge generation is allowed. The company currently operates within the authorized limit for paint sludge generation, whereas phosphate sludge generation

(Hazardous Waste) is a concern as it is approaching the acceptable limit. Moving forward, an inherent risk is associated with a 20% increase in production volumes, which could further increase waste. Thus, the project aimed to reduce average phosphate sludge generation from 6.92 g/sq.m to 4 g/sq.m.

Quality Tools, Techniques and Methodologies Utilized:

This study used the Six Sigma DMAIC methodology to solve the problem. Gauge R&R study was used for the Measurement System Analysis (MSA). Root cause analysis methodology is used to identify potential causes. An innovative method of *drying bed* technology is installed to address this high moisture content (root cause) in phosphate sludge. In an effort to reduce the sludge, the team actively sought out new-generation pre-treatment chemicals. The team used compact & fine phosphate coating chemicals from R&D activities. Further, critical quality tools such as MSA, pugh matrix, process capability studies, hypothesis testing (2 sample t-test), variable control charts, and risk analysis were effectively used.

Benefits achieved from the Sustainable Performance lens:

As a result, there was a notable decrease in mean phosphate sludge generation from 6.92 g/sq.m to 5.22 g/sq.m. Furthermore, the mean phosphate sludge generation was reduced from 6.92 g/sq.m to 4 g/sq.m. The phosphate coating weight process exhibits stability and capability with a process performance index(Ppk) of 1.83. Further progress was achieved, the phosphating process time was reduced from 90 sec to 60 sec, and productivity was improved by 12%. Moreover, the water requirement was significantly reduced from 180 KL to 120 KL annually. The financial benefit of 64K USD is realized. More importantly, it reduces carbon footprint because of reduced energy consumption. However, with these efforts company believes that UNSDG 12 (Responsible Consumption and Production) was achieved.

Implications for Managers:

It is important to note that QM management with Innovation provides better results aligned with the SDGs. Also, R&D activities must be integral to the quality initiative involving technical components. Risk analysis is a critical and effective tool to ensure sustainable solutions.

Key Lessons Learned:

The key lessons from this case study are the importance of QM tools to meet sustainable development goals. In this case, goal 12 ensures sustainable consumption and production patterns. There is a clear indication of substantial sludge generation savings in the painting process, resulting in financial benefits, reduced energy consumption, and reduced carbon footprint.

4.4. Within Case Analysis of Company D:

Brief Description of the Company:

Company D was established in 2002 in China and is now a listed combustion engine company in Hong Kong and China Stock markets. In 2022, Company D's sales revenue was 24 billion USD, and its net income was 1 billion USD. The company focuses on product-driven and capital-driven operations. It has developed products with three core competencies: quality, technology and cost. Its products are exported to more than 110 countries and regions.

Problem Statement and its Alignment with UNSDGs:

The project's main aim is to use key technologies and applications of energy conservation and emission reduction for heavy-duty commercial vehicles. Emissions from heavy-duty commercial vehicles are one of the leading causes of the excessive concentration of NOx and particulate matter. According to statistics, heavy-duty commercial vehicles in China bear 77% of the freight transport and 81% of the passenger transport. Fuel consumption accounts for 50% of the total vehicle fuel consumption, of which NOx and particulate emissions account for more than 60% and 80%, respectively. Therefore, reducing the fuel consumption of heavy-duty commercial vehicles is of great significance.

Quality Tools, Techniques and Methodologies Utilized:

The project uses the 8D problem-solving workflow method, benchmarking analysis, SWOC analysis, causal analysis chart and regression analysis for specific analysis and improvement. By benchmarking well-known international brands of commercial vehicles, the company unearthed its shortcomings, established the project's goal, and gradually transformed from following to leading through continuous optimization. Quality analysis tools such as causal analysis charts are used to analyze and solve the root causes of high fuel consumption, mainly fuel consumption of engine body, poor driving habits, and unreasonable application conditions of vehicle matching. The main measures taken by the company include engine and vehicle optimization, driver's driving behaviour optimization, and vehicle matching application

research. Through innovation and R&D activities, better fuel consumption technology and parameters are developed. Based on many sample vehicles, the company found that driving behaviour significantly influences the outcome. Thus, a regression analysis method establishes the driving behaviour model. Moreover, the company researched the operating characteristics of different market segments based on the operating conditions of engines with different loads and unpredictable road conditions. It guided users to choose an engine and vehicle reasonably according to the market segments.

Benefits achieved from the Sustainable Performance lens:

Through the optimization of vehicle aerodynamics and drive system, vehicle fuel consumption is reduced by 5% - 7%. This result shows that a heavy-duty commercial vehicle could save more than 20 tons of fuel and reduce 55 tons of CO_2 emissions in its life cycle, equivalent to an economic benefit of about 14K USD. Based on the annual production and sales of 300,000 heavy-duty vehicle engines, the company's vehicles can save 6 million t/a of fuel and reduce 16.5 million t/a of CO_2 emission. The second result was that during the implementation of the project, five patents for invention, one technology secret, two enterprise specifications and two papers were obtained. Eventually, the project contributed to the UNSDG 12 (Responsible Consumption and Production) and UNSDG 3 (Good Health and Well-being)

Implications for Managers:

QM tools can be effectively used to meet sustainable development goals by reducing the fuel consumption of heavy-duty commercial vehicles. The tools such as benchmarking analysis, 8D problem-solving ideas, TQM and lean thinking, data analysis, causal analysis chart and regression analysis should be implemented through an interdepartmental team to achieve good results. It is critical to note that behaviour analysis and technical parameter optimization provide better results in quality and sustainability initiatives. Thus, behavioural studies are a new area to be included in the QM projects linked to UNSDGs.

Key lessons learned:

Benchmarking and SWOC analysis can be considered readiness factors before quality improvement initiatives. Modelling and optimizing non-technical, especially human factors, is critical in quality projects. Multi-functional interdepartmental teams are critical for QM projects.

4.5 Within Case Analysis of Company E:

Brief Description of the Company:

The company's roots may be traced back to the 1990s when it was founded in China as a special steel production organization. It is one of the National Torch Program's most important high-tech initiatives. The company's annual special steel production capacity is 6.9 million tonnes. It serves clients in more than 60 countries and regions with a wide range of special steel products across many categories and requirements and a comprehensive suite of support services. The firm has received several awards for its superior goods and services. To fulfil the 17 UNSDGs, the firm is dedicated to executing the sustainable development strategy and proactively enhancing its environmental protection system. The corporation signed the United Nations Global Compact in August 2016 and pledged to continue executing the sustainable development strategy.

Problem Statement and its Alignment with UNSDGs:

The nation is responsible for 28% of the world's emissions; thus, energy conservation and emission reduction are a top concern for the country and the corporation. Since the firm signed the pact of contributing to the UNSDGs, it must execute eco-friendly projects. According to the calculations, the sulphur dioxide, nitrogen oxides, and particulate matter emissions from the iron and steel industry in 2017 were 1.06 million tonnes, 1.72 million tonnes, and 2.81 million tonnes, respectively, accounting for 7%, 10%, and 20% of the country's total emissions, which is one of the primary sources of air pollution in the country. Thus, the company has established an energy conservation and emission reduction project for the special steel smelting and rolling process, which seeks to achieve ultra-low air pollutant emissions and ultra-low energy consumption.

Quality Tools, Techniques and Methodologies Utilized:

Through benchmarking analysis, ultra-low emission transformation of 360 m^2 sintering is achieved. Six Sigma methodology helped to reduce unit gas consumption of reheating furnace. VOC analysis, VSM, MSA, CE matrix, FMEA, hypothesis testing, DOE and control chart are effectively utilized. The multi-response optimization methodology is used to achieve practical results.

Benefits achieved from the Sustainable Performance lens:

The initiative has yielded economic and social advantages for the firm. Reduced particulate matter, sulphur dioxide, and nitrogen oxide emissions are estimated at 256 t/a, 758 t/a, and 1,480 t/a, respectively, equating to an economic gain of about RMB 14.84 million. Based on a 7.9 percent year-over-year increase in crude steel output, the total natural gas consumption decreased by 3 million m^3, the freshwater consumption decreased by 3.2 million tonnes, the total energy consumption per tonne of steel decreased by 5.7%, the total power consumption per tonne of steel decreased by 2.4%, the natural gas consumption per tonne of steel decreased by 13.39%, and the freshwater consumption per tonne of steel decreased by 13.39%. From a social standpoint, the Ministry of Industry and Information Technology selected the firm for the first batch of green factories. In addition, it was awarded the State Scientific and Technological Progress Award and granted three patents. Eventually, the outcomes are acknowledged by the UN Global Compact. UNSDG 3 (Good Health and Well-being) and UNSDG 9 (Industry, Innovation and Infrastructure) are achieved through emission reduction. Also, the energy conservation effect promoted UNSDG 7 (Affordable and Clean Energy). In addition, patents and honours contributed towards UNSDG 8 (Decent Work and Economic Growth). Besides, the company's selection into the list of the first batch of green factories promoted UNSDG 12 (Responsible Consumption and Production).

Implications for Managers:

For integrating continuous improvement projects with UNSDGs, selecting comparable indicators and reference values through benchmark analysis is vital. Moreover, MSA is crucial for measuring whether the process is effective and improving. Among the five properties (bias, linearity, stability, repeatability and reproducibility) of the measurement system, the influence factors of repeatability and reproducibility are well considered in the Project and the key to solving the problem. It is apparent from the case study that Green technology implementation leads to better adoption of UNSDGs. However, it is essential to note that financial and personnel inputs are crucial for the transformation of any firm towards UNSDGs attainment.

Key Lessons Learned:

Since 2019, the company has carried out 18 Six-sigma projects, with a total economic benefit of 8 million USD, making the Six-sigma methodology widely used in quality improvement, output improvement, production equipment efficiency and other aspects. This indicates that Six Sigma can be effectively used to attain UNSDGs. Thus, developed Green technology was

effectively applied to 60 more companies due to the clustering system in the nation. Table 1 provides a summary of withing the case analysis.

4.6 Critical Reflections Using Cross-Case Analysis

India and China are taking proactive steps to improve the quality of life and earth by promoting quality initiatives in line with the UNSDGs. Indian manufacturing firms are leading in this direction, possibly due to the early adoption of a QM culture. However, it is interesting that China promotes the integration of quality and sustainability through its policies and financial support.

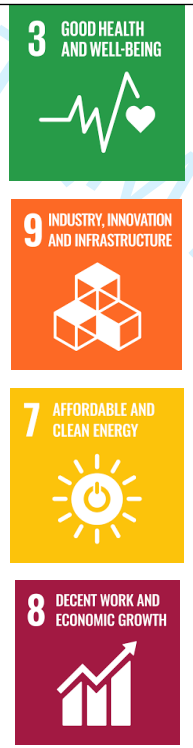
From the perspective of methodologies, TQM and Six Sigma methodologies are more frequently used OPEX strategies to execute the projects. It is important to note that whenever Six Sigma is utilized, DOE techniques are used to improve the process. Further, MSA and C&E analysis is the most frequently used tools across all the case studies as projects are executed in the manufacturing industries. Four case studies contributed to UNSGD 12 (Responsible Consumption and Production), emphasizing its relevance to manufacturing industries and quality initiatives in the organization. Further, it is interesting that the Indian industries use Innovation as a new intervention in attaining UNSDGs through OPEX strategies. On the other side, case studies executed in China have used Green technology and Behaviour modelling as an additional intervention to achieve the UNSDGs. Table 2 provides a summary of cross-case analyses.

Table 1: Summary of within Case Analysis

Case Study	Objective	Methodology/ Tools Used	UNSDGs Addressed	Results Achieved	Key Takeaways/ Implications
A	To reduce the RRC of PCR Tyres yearly and achieve a 35% reduction in a typical tyre size within six years	• Kaizen • Task Achieving QC Story methodology for achieving the yearly targets. • TQM Continual Improvement Framework • DOE (Classical and Taguchi) • AHP • ANOVA • Hypothesis testing • Simulation		• Launched the product one year ahead of the target • 37.5% improvement in RRC • 37% reduction in carbon footprint	• Policy Deployment ensures top management commitment • Simulation and Rapid Prototyping help the optimal utilization of resources • Taguchi's Robust Design Approach ensures product launch ahead of time • Cross-functional teams help in continuous improvement • Kaizen events bring confidence to the project team and stay motivated
B	To use energy-efficient products to improve energy productivity and improve	• Six Sigma • DOE • Root cause analysis		• CO_2 savings of 7583 tons • Electricity savings of 10.7 million kWh	• Internal quality philosophy and models help to integrate quality and sustainability projects.

Case Study	Objective	Methodology/ Tools Used	UNSDGs Addressed	Results Achieved	Key Takeaways/ Implications
	renewable energy share.			• Cost Savings of Rs 90 million	• Internal QM institutions foster the adoption of contemporary continual quality improvement methodology and quality culture. • Proficiency in analytical tools is critical for the projects. • Project management skills are essential.
C	To reduce the phosphate sludge generation	• MSA • Pugh matrix • Process capability studies • Hypothesis testing (2 sample t-test) • Variable control charts • Risk analysis		• Reduction in the mean of phosphate sludge generation from 6.92 g/sq.m to 4 g/sq.m • The phosphate coating weight process is stable and capable as Ppk is 1.83.	• The use of MSA and other tools to identify the root cause of the problem. • The use of QM methodologies to reduce hazardous waste generation. • The importance of disseminating success stories within the organization to

Case Study	Objective	Methodology/ Tools Used	UNSDGs Addressed	Results Achieved	Key Takeaways/ Implications
				• Reduction in the phosphating process time from 90 sec to 60 sec. • Improvement in productivity by 12%. • Decrease in the water requirement from 180 KL to 120 KL per annum. • Financial saving of INR 5.25 million.	improve the overall morale of the organization.
D	To reduce the fuel consumption and CO_2 emission of heavy-duty commercial vehicles	• 8D Problem solving • Regression • Benchmarking • Casual Analysis Chart • Optimization • TQM concepts • Lean Thinking		• Saving 6 million tons of fuel • Reduction of 16.5 million tons of CO2 emissions	• Benchmarking and SWOC analysis can be considered readiness factors before quality improvement initiatives. • Optimization of non-technical, especially human factors, plays a critical role in quality projects.

Case Study	Objective	Methodology/ Tools Used	UNSDGs Addressed	Results Achieved	Key Takeaways/ Implications
					• Behavioural studies add value to the improvement projects • Multi-functional interdepartmental teams are critical
E	To reduce the energy conservation and emission of special steel smelting and rolling process	• SIPOC process and flowchart • MSA system • VoC and Benchmarking • C&E Matrix • FMEA • Six-sigma methodology • Root causes analysis • DOE • Control Charts		• The emission of particulate matter is reduced to 256 tons/year(reduction rate of 93%; Sulphur dioxide is reduced to 758 tons/year(reduction rate of 92%); The emission of nitrogen oxides is about 1480 tons/year(reduction rate of 76%); Economic benefit is about RMB 14.84 million; • Natural gas consumption decreased by 3 million m^3.	• Benchmarking processes are critical to achieving quality and sustainability goals. • Adoption of Green Manufacturing Technology will help to integrate quality and sustainability • Financial inputs, personnel input, equipment input and the Six Sigma team are essential for the firm's transformation towards attaining UNSDGs.

Case Study	Objective	Methodology/ Tools Used	UNSDGs Addressed	Results Achieved	Key Takeaways/ Implications
				The water consumption decreased by 3.2 million tons, and the comprehensive energy consumption per ton of steel decreased by 5.7% • The company was selected for the list of the first batch of green factories by the government. • The company formed three patents and won the First Prize Award.	

Table 2: Cross-Case Analysis

Country	Case Studies	Sector	Industry	UNSGs Targeted	Key OPEX Principles Used	Most Frequent Used QM Tools	Additional Interventions
India	A, B, C	Manufacturing	Automobile and Allied	7, 11, 12 (Twice), and 13 (Twice)	TQM, Kaizen, Six Sigma	DOE, MSA, and C&E analysis	Innovation, Simulation, and Rapid Prototyping
Republic of China	D, E		Transportations and Processing	3 (Twice), 7, 8, 9, and 12 (Twice)	Lean Thinking, Six Sigma and TQM	C&E analysis, DOE, MSA, and Inferential statistics	Green Technology, Behavioural modelling, and Market Analysis

5. Discussions

Connecting the activities of all the stakeholders is necessary to build a better society and safeguard Mother Earth. It has been noted that companies are making significant efforts to enhance the quality of their product or service by using OPEX techniques. Nevertheless, companies may also make a difference in society by aligning their quality improvement initiatives with the UNSDGs. From this perspective, the primary objective of this study was to investigate the significant influence of QM principles and tools on sustainable development. Indeed, the study's findings show that companies have substantially improved products or services by linking the QM projects to UNSDGs. This integration yielded overall improvement in sustainability measured in terms of environmental, financial, operational and social performance. Our study has confirmed the hypothesis proposed by Ali et al. (2021) and Powell et al. (2017) concerning the positive impact of OPEX methodologies, especially Lean and Six Sigma, on operational and environmental performance. The case studies presented are better examples in this direction.

Adopting QM tools and techniques in industries may substantially impact environmental protection. This is evident from the case studies, as companies effectively leveraged QM tools to address their carbon footprint. Company A decreased the environmental impact by 37%; compared to previous results, the carbon footprint reduction was almost 50% in enhancing a diary process (Trubetskaya et al., 2023). The difference could be rooted in the specific focus solely on the environmental aspect and the manufacturing sector's process complexity compared to the food industry. A CO_2 savings of 7583 tons in Company B has been achieved by using the Six Sigma approach, as well as a 16.5 million tons reduction in CO_2 emissions in Company D. Compared to previous results, the saving of CO_2 was 1630.08 kg when applying the DMAIC method in the retail sector (Marrucci et al., 2020). More importantly, there was a notable decrease in phosphate sludge generation in Company C by optimizing the existing process. This reflects the company's commitment to sustainable manufacturing practices and reasonable waste management.

Furthermore, material consumption was significantly reduced in several case studies. A prominent annual reduction in 60 KL water was achieved in Company C, while Company E reduced freshwater consumption by 13.4%. Additionally, there has been a tangible reduction in vehicle fuel consumption of 5-7% in company D which signifies the positive advancements in environmental sustainability and energy consumption. On the other hand, adopting QM has

yielded improved productivity and process capability and resulted in a substantial reduction in processing time. From the economic viewpoint, this study demonstrates a financial saving of RS 10 million and INR 5.25 million in companies B and C, respectively, which would not have been possible without using QM tools.

These case studies received awards for their integrated effort of continual quality improvement approach through OPEX strategies in line with the UNSDGs. Undoubtedly, being Quality Sustainability Awarded will elevate the company's reputation and competitiveness in the global market, solidifying its position as the leader in sustainability. The findings indicate that the effective use of quality methods and tools, a clear link to the organization's vision and project objectives, and an innovative approach to sustainability are critical to the sustainability-linked OPEX projects. These results attest to the critical importance of integrating these aspects, as argued by Makhlouf *et al.* (2023). Moreover, reliable and outstanding results were achieved since the project linked the quality initiative with the UNSDGs during the project charter preparing phase. Besides, these case studies aimed to leverage the results to other products/processes/organizations, which helped them cling to the awards and achieve the desired results. This indicates that a broader perspective is essential while integrating OPEX with UNSDGs.

Furthermore, most case studies targeted more than one UNSDG through their projects. This indicates that if the companies link their quality improvement initiatives to sustainability, each project can contribute to more UNSDGs. Indeed, Isaksson *et al.* (2023) call for a holistic view of the SDGs as a whole system to deal with environmental, social and business issues. The case studies achieved their goals since they indicated how the project's results could be leveraged for other projects within or outside the organization. Also, the project team clarified how statistical techniques can be used correctly and coherently with objectives. Most of the case studies utilized OPEX strategies to achieve the objectives.

Interestingly, the Indian automobile industries are at the forefront of ensuring sustainable manufacturing. Furthermore, UNSDG 12 (Responsible Consumption and Production) is the most targeted goal (4 times). In addition, automobile industries are targeting UNSDG 13 (Climate Action) more frequently. Across all the case studies, quality methods and tools were applied thoughtfully, ranging from simple approaches such as VOC to more robust and

sequential approaches such as Six Sigma. Thus, selecting methodology and tools in sustainable quality projects depends on the type of UNSDGs to be attained.

It is noteworthy that Innovation and R&D activities, if integrated into the QM projects, produce more sustainable results. Further, adopting green technology can significantly contribute to the UNSDGs in an OPEX project. Besides, it is learnt that behavioural modelling and optimization play a critical role in achieving productivity and performance, which is usually neglected in most OPEX projects.

6. Conclusions

The study analyzed the contribution of five companies to UNSDGs in the two most populous and emerging manufacturing hubs of Asian nations, India and China. Pollution and emissions are a clear side effect of a growing human population and industrial sector. However, evidence from the case studies shows that both India and China are actively working to advance the UNSDGs and enhance their respective societies. The study validates that QM philosophies can be effectively integrated with SDGs. Moreover, it indicates that methodologies and tools can effectively achieve UNSDGs when the industry has an established quality culture. It is interesting to note that *Innovation* acts as a liaison while integrating the UNSGDs with QM in the companies. Thus, *Innovation and QM* will be the new theme for the research for academicians.

Manufacturing organizations would benefit the most from focusing on UNSDG 12 (Responsible Consumption and Production). This research shows, however, that due to the interconnected structure of manufacturing activities, even a single QM project may be related to multiple UNSDGs. Thus, UNSDGs can be taken as the KPIs in the OPEX framework in the industries. Also, it is evident that the selection of QM tools and techniques depends on the type and challenges associated with the UNSDGs to be addressed. Design of Experiments (DoE), Measurement Systems Analysis (MSA), Root Cause Analysis, and Inferential Statistics were shown to be the most often employed quality methods. Further, the study shows that Industry 4.0 technologies can play a vital role in integrating QM and UNSDGs, assisting in informed decision-making.

This article makes a novel contribution to the current knowledge base by critically analyzing projects' success stories supported by the IAQ in integrating quality initiatives with the

UNSDGs. Moreover, it highlights the standard tools that assist in UNSDG-linked quality initiatives. Lessons learned, and managerial implications from the case studies could be generalized and helpful for companies and policymakers. Further, these case studies can persuade practitioners and quality improvement teams to initiate OPEX projects from the perspective of society and mother nature.

The project is limited because it has analyzed only five case studies. However, it is essential to note that all the case studies were nominated for the IAQ Quality Sustainability Award and other national awards. This ensures the credibility and robustness of the inferences drawn based on these case studies. Nevertheless, the authors are intended to adopt mixed-method research to bring more insights into integrating quality projects into UNSDGs. Moreover, Action Research or Design Science Research methodology could help the academicians develop a comprehensive roadmap for deploying quality-linked UNSDG projects.

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